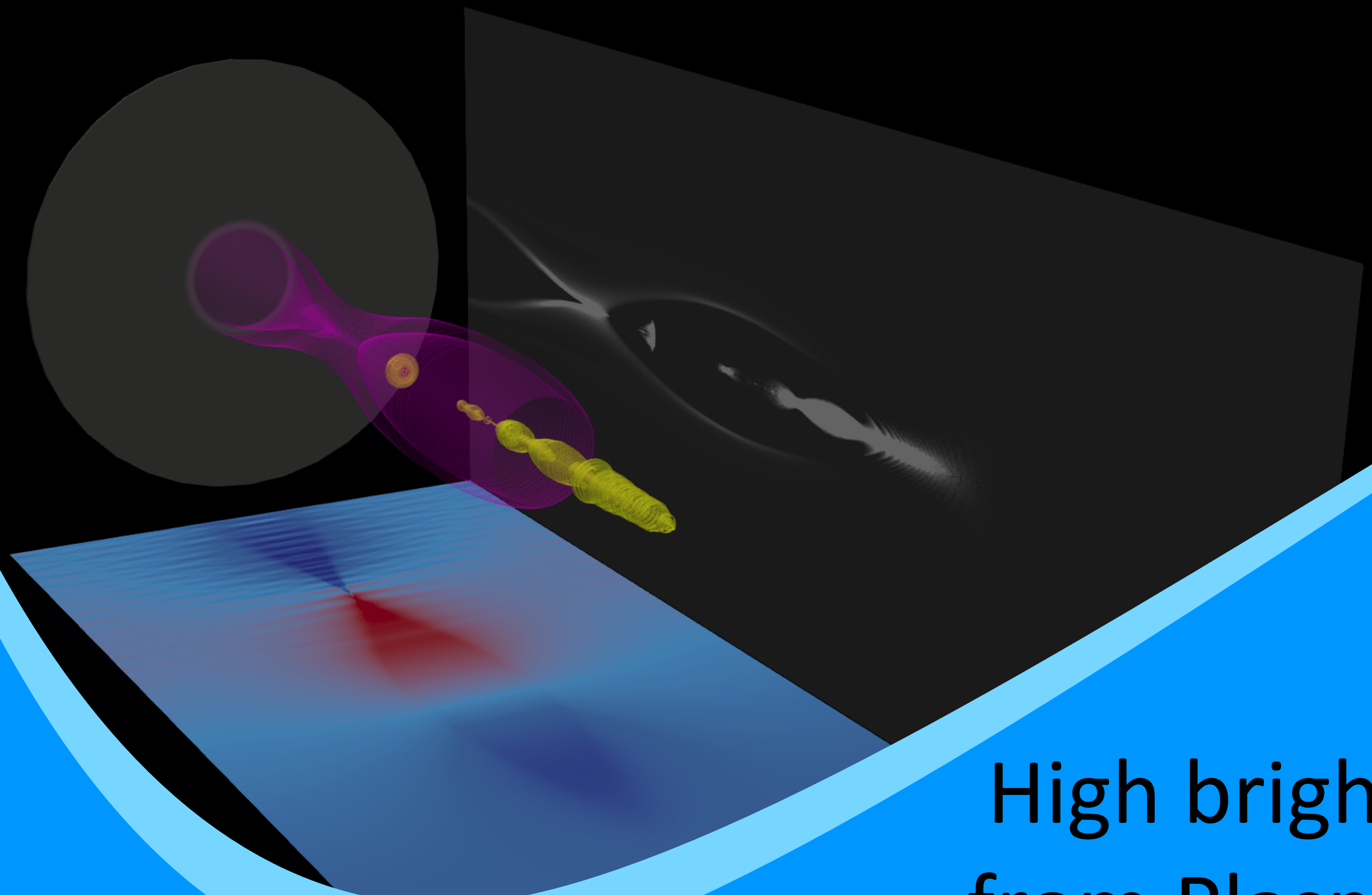
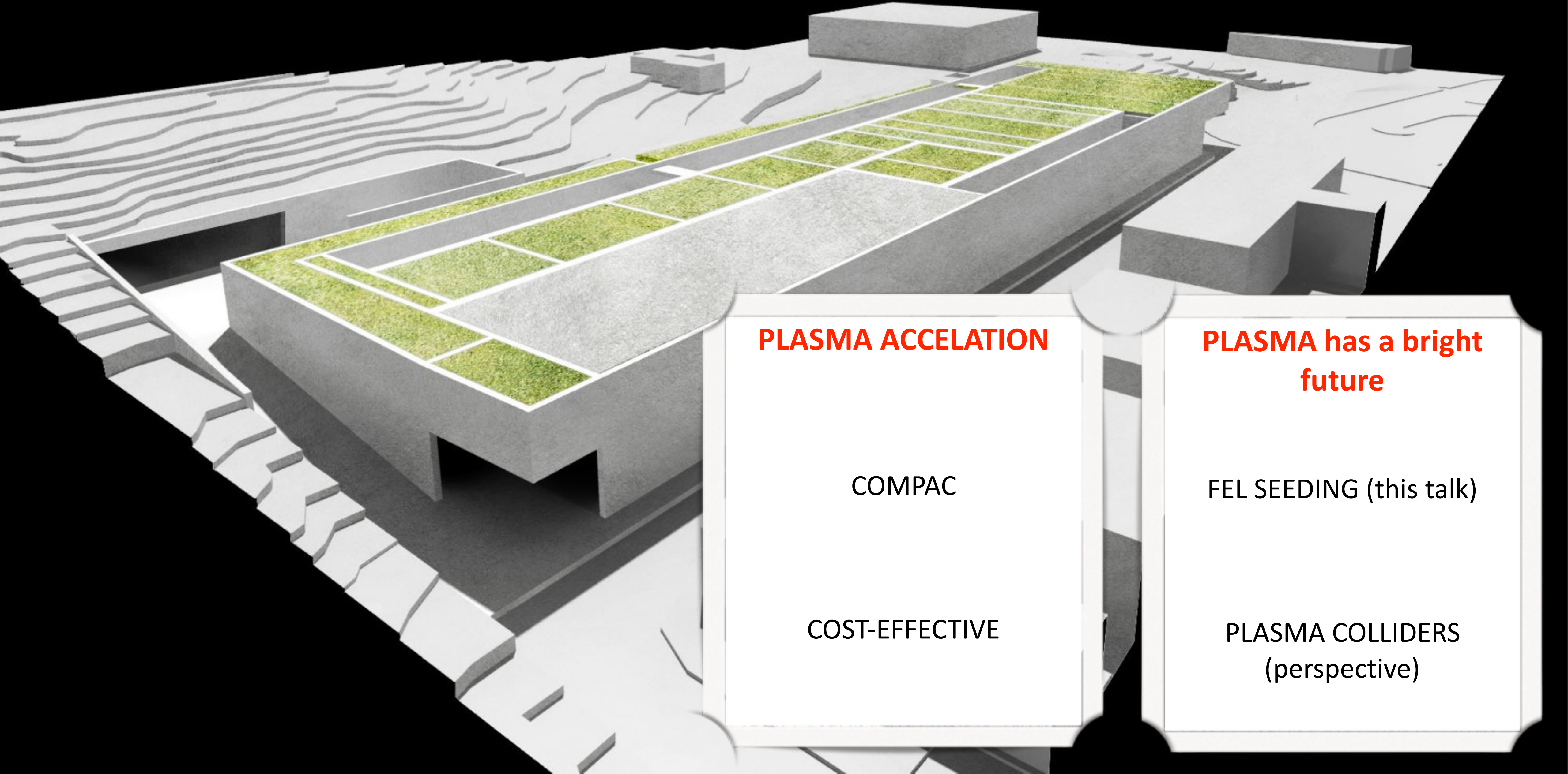


High brightness electron beams from Plasma Based Acceleration

Alberto Marocchino
LNF-INFN Frascati Italy

on behalf of the Sparc_Lab collaboration

EuPRAXIA@SPARC_LAB



PLASMA ACCELATION

COMPAC

COST-EFFECTIVE

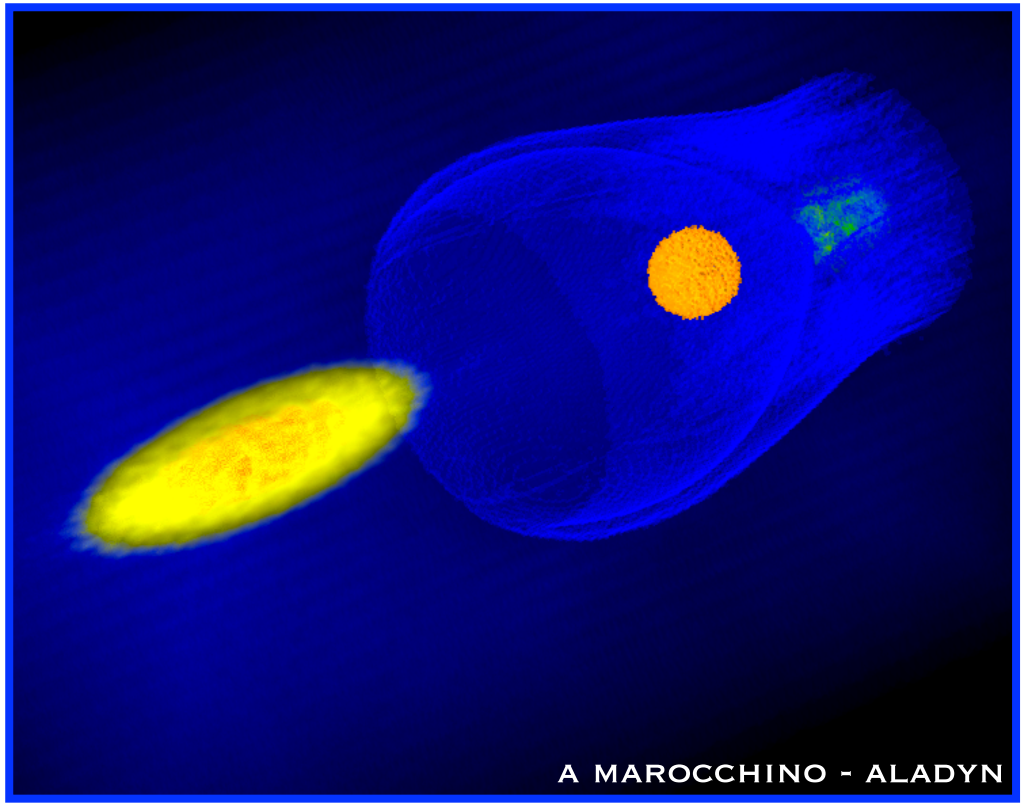
PLASMA has a bright future

FEL SEEDING (this talk)

PLASMA COLLIDERS (perspective)

Presentation Layout

- Beam Driven Plasma Acceleration
- EuPRAXIA@SPARC_LAB
- Realistic *start-to-end* simulations:
  - from bunch Generation to Application
  - High brightness
  - 1.1 GV/m acc gradient and no quality depletion
- Experiments at SPARC_LAB and Code Benchmarking

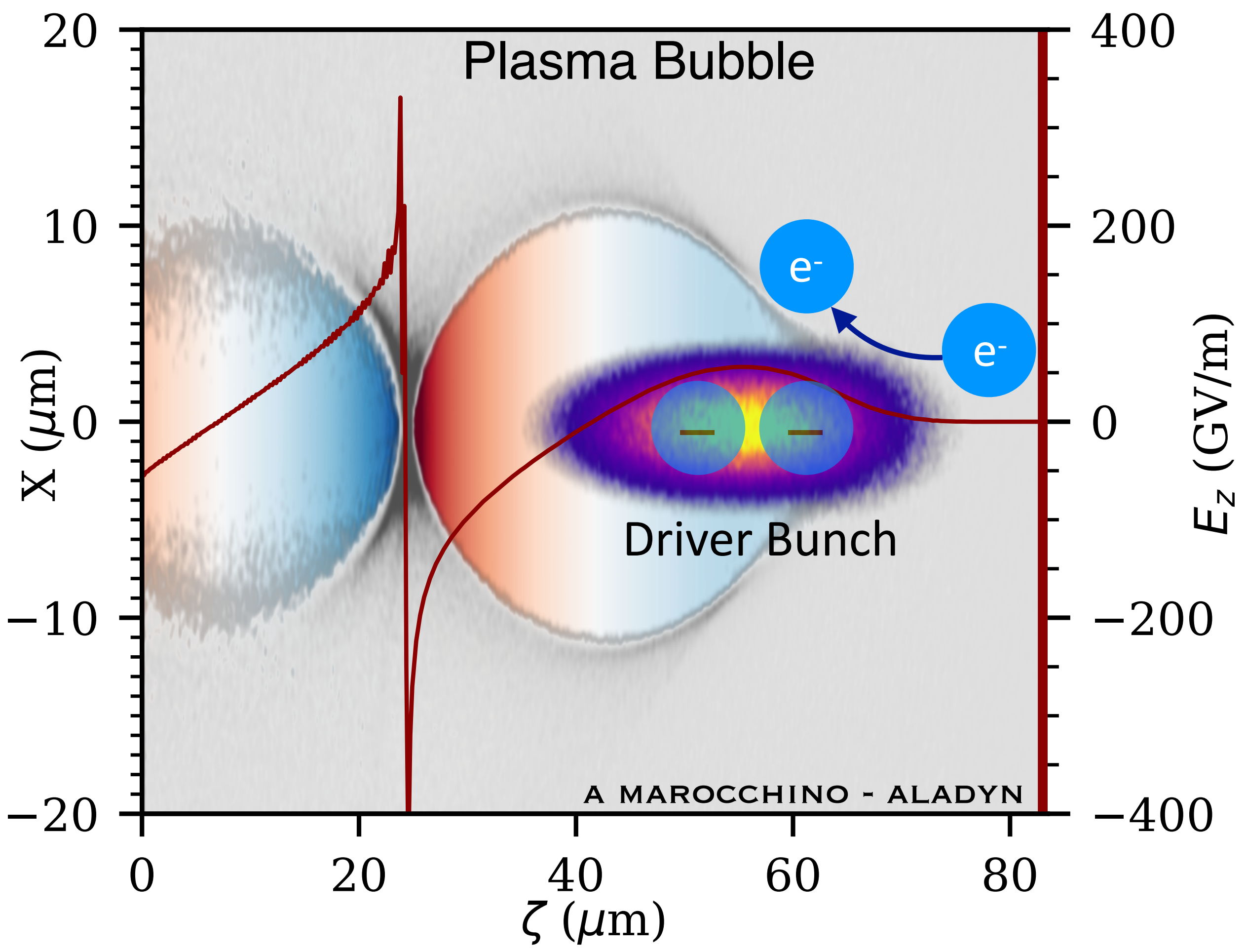


Beam Plasma Acceleration

Physics Mechanism

- Coulomb repulsion

Process Visualisation

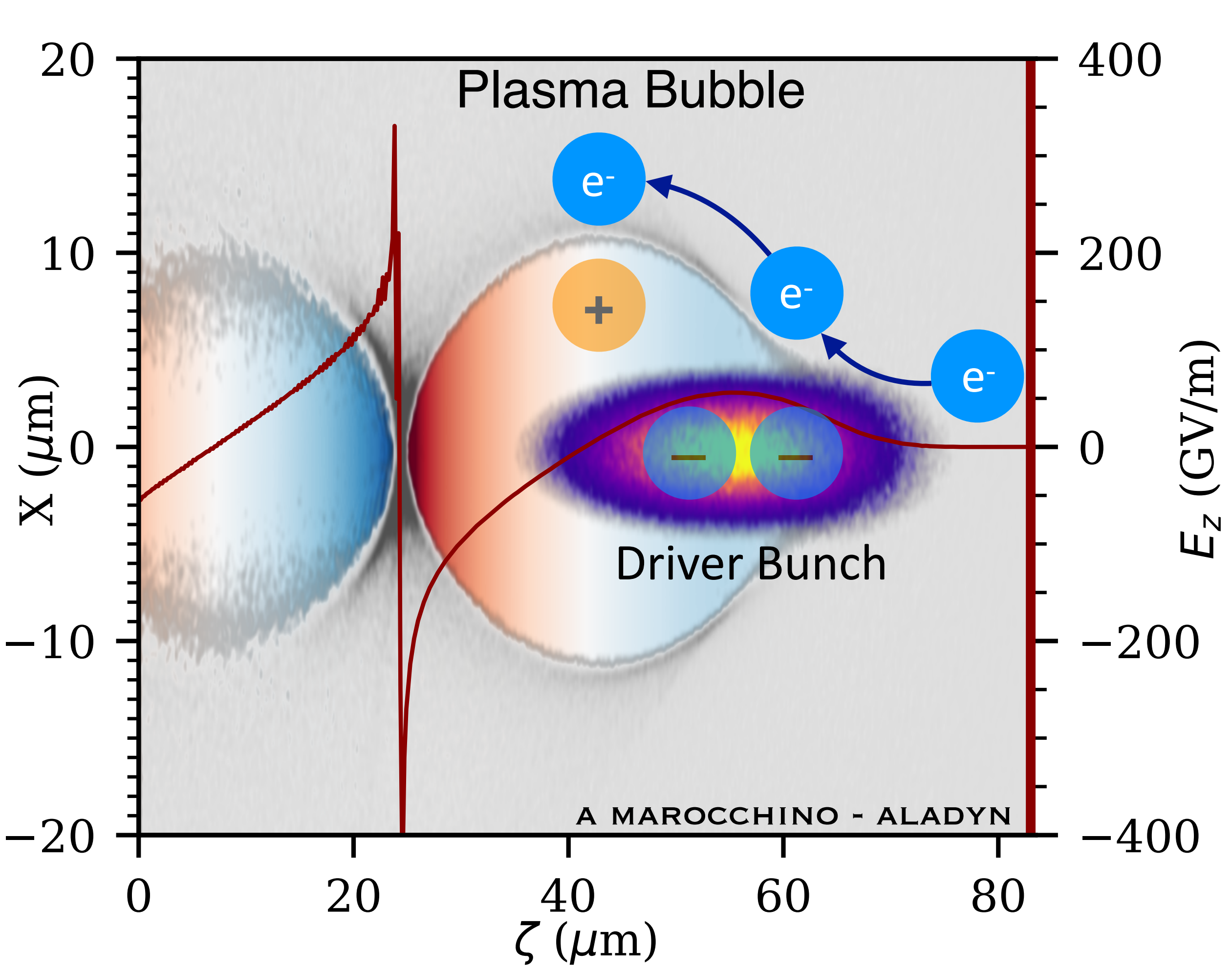


Beam Plasma Acceleration

Physics Mechanism

- Coulomb repulsion
- Bubble generation :: positive charge

Process Visualisation

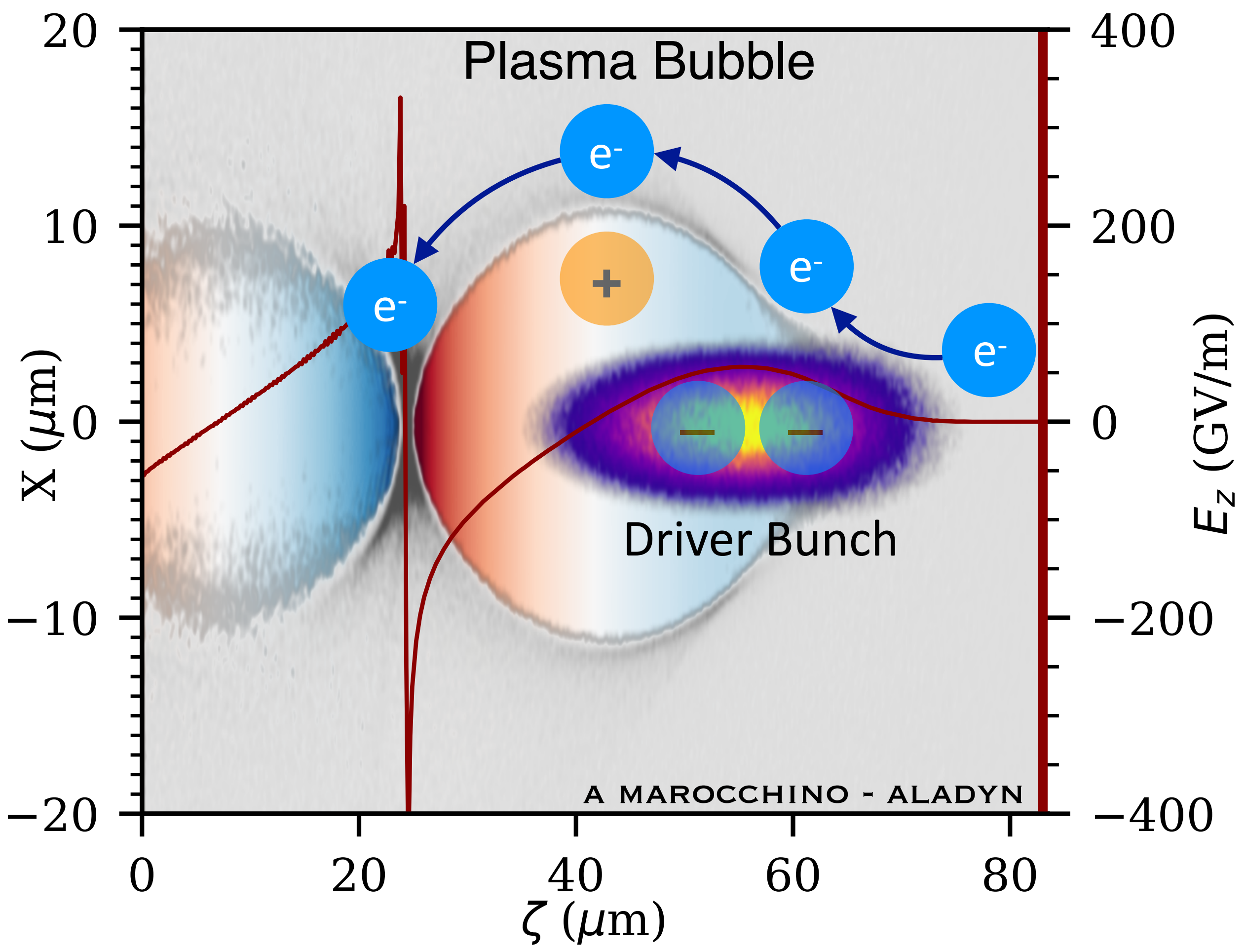


Beam Plasma Acceleration

Physics Mechanism

- Coulomb repulsion
- Bubble generation :: positive charge
- Coulomb attraction :: bubble closure

Process Visualisation

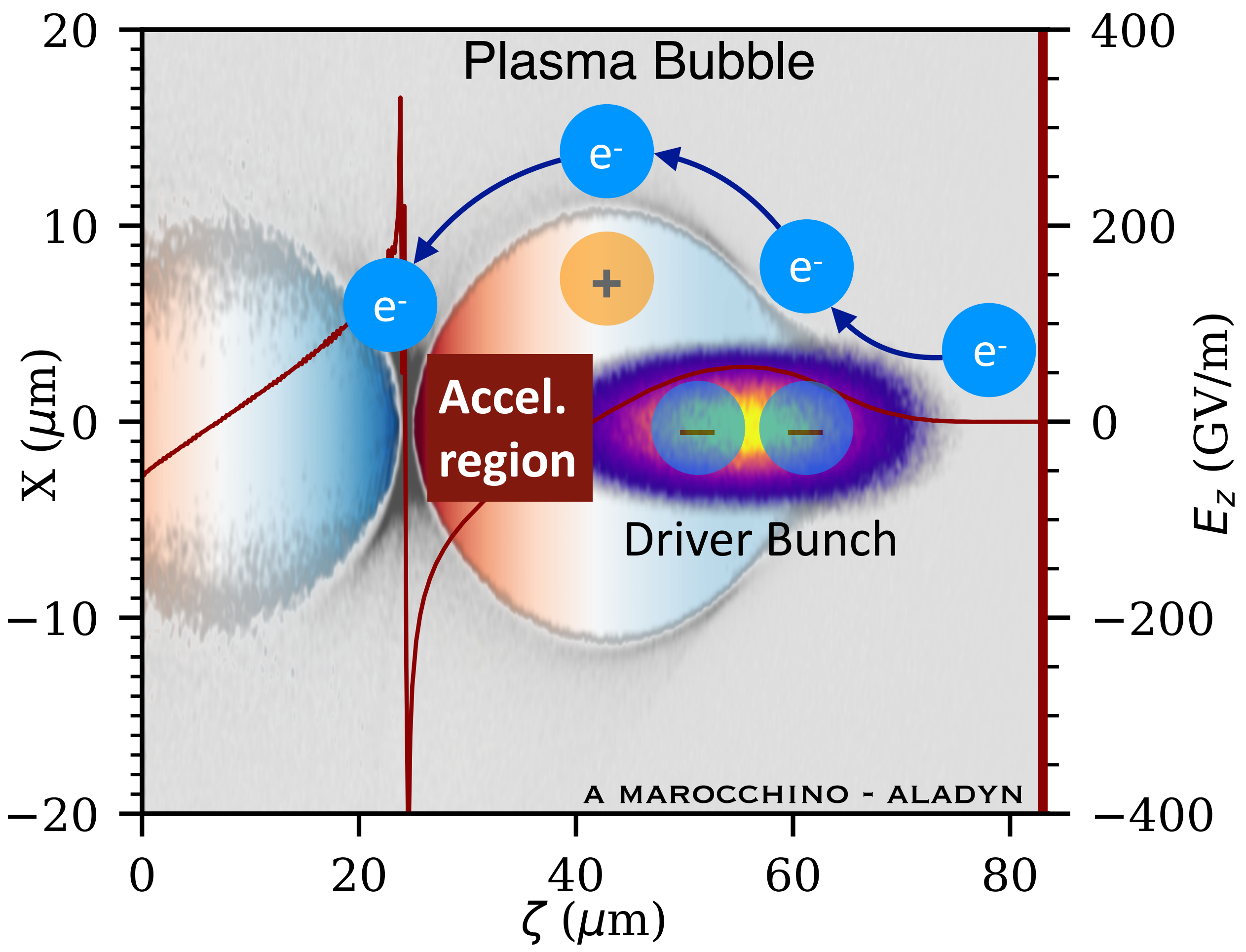


Beam Plasma Acceleration

Physics Mechanism

- Coulomb repulsion
- Bubble generation :: positive charge
- Coulomb attraction :: bubble closure
- the ion bubble generates a *strong* accelerating field

Process Visualisation



Plasma Acceleration Parameters

The Plasma dependance

- the bubble length:

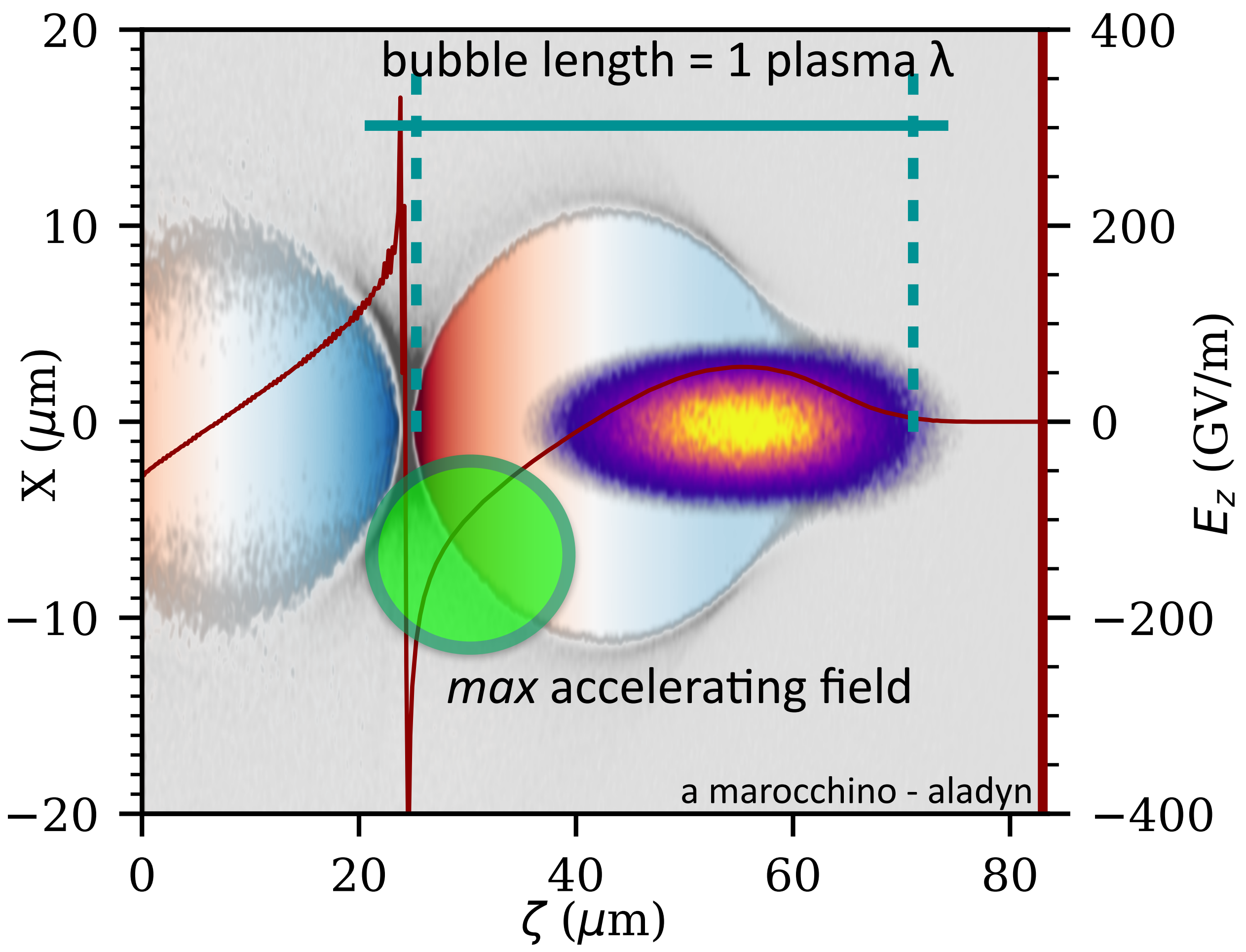
$$\lambda_p = 2\pi/\kappa_p = \sim 1/\sqrt{n_p}$$

- The maximum electric field:

$$E_{max} \sim \sqrt{n_p}$$

(cm^{-3})	10^{16}	10^{17}
λ_p	330µm	104µm
E_{max}	10 GV/m	30 GV/m

our reference value



A. Marocchino et al. NIM-A 2018

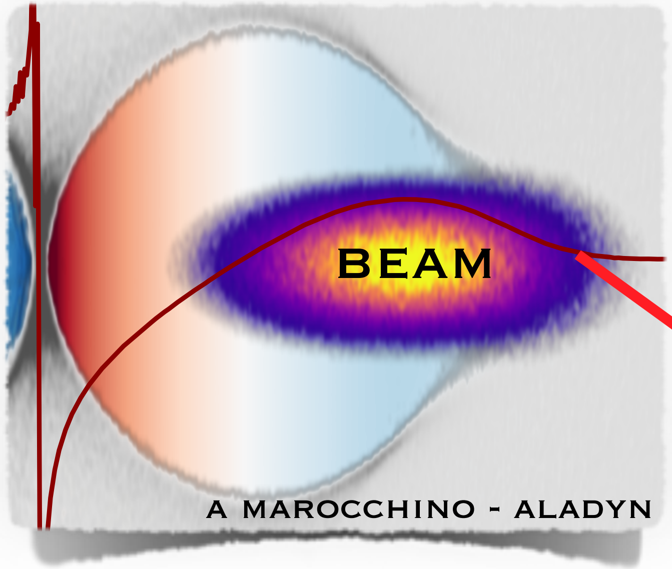
Beam VS Laser Driven

Plasma Wakefield Schemes

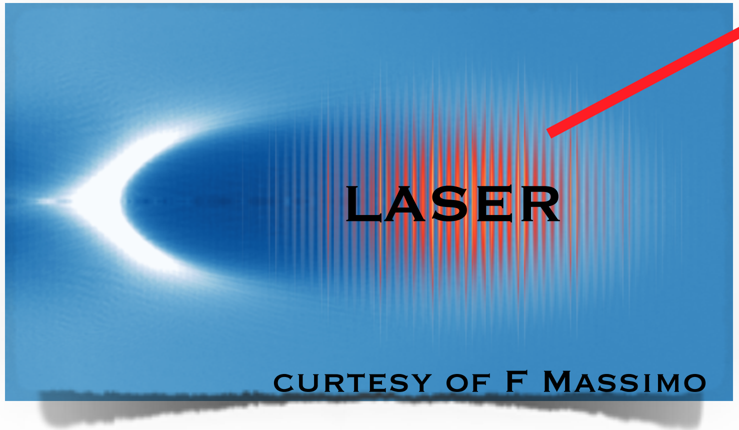
- the driver could either be:
  - Laser Pulse
  - Charged bunch (electrons, positions, protons)

our choice

- Beam advantages:
  - longer depletion lengths
  - require no guiding
  - no driver-trailing bunch dephasing
  - higher energy transfer

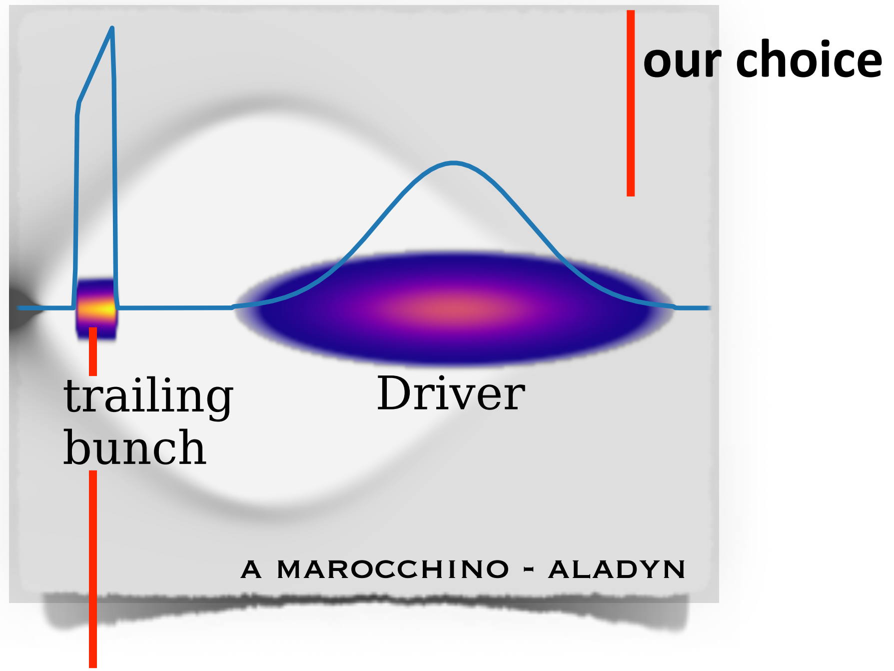


Drivers



external VS internal injection

external



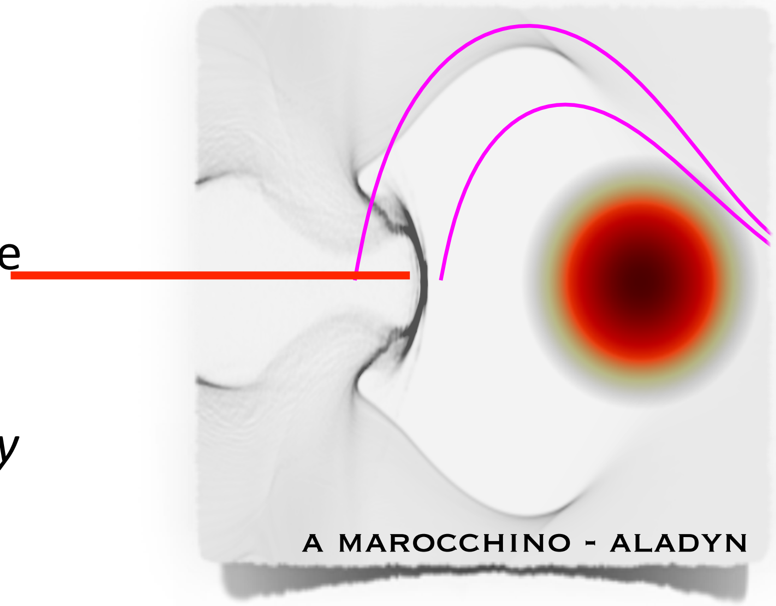
- externally produced (photo-injector)
- placed right phase
- higher degree of control
- generated with the required *shape* or *quality*

A. Marocchino et al. NIM-A 2018

internal

Generated internally by the plasma

e.g. by a density bump



- suffers from shot-to-shot large fluctuations (e.g. gas nozzle-blade)
- trailing bunch of *poor quality*

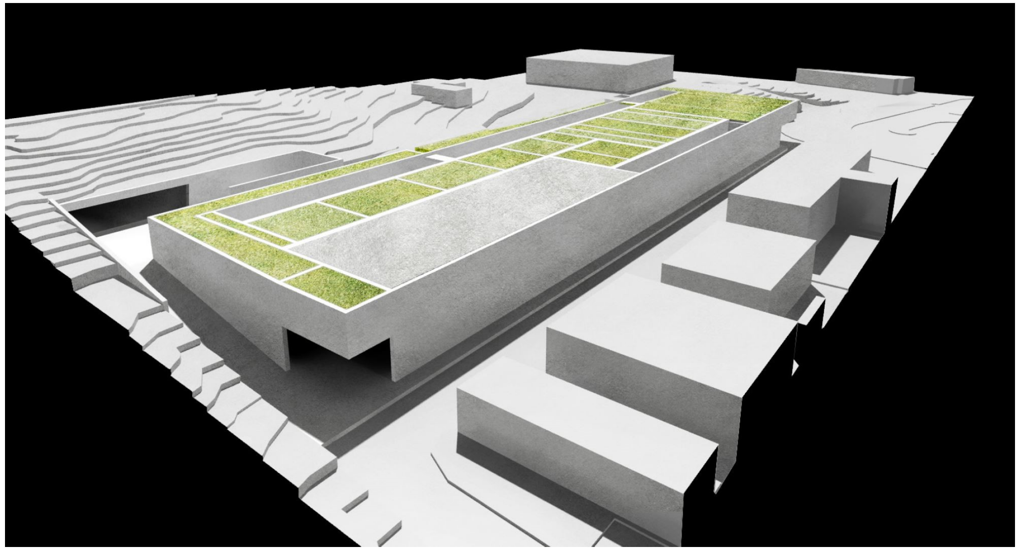
F. Mira & A. Marocchino NIM-A 2018

EuPRAXIA@SPARC_LAB

- ***EuPRAXIA*** is an European project that ***will bridge the gap between successful proof-of-principle experiments and ultra-compact accelerators for science***

- **EuPRAXIA@SPARC_LAB** is the future Frascati-LNF facility for PWFA experiments
  a unique facility that is being built on 3-pillars:
  - large plasma **accelerating gradients**
  - acceleration with **little trailing bunch depletion**
  - **FEL lasering** with a plasma accelerated bunch

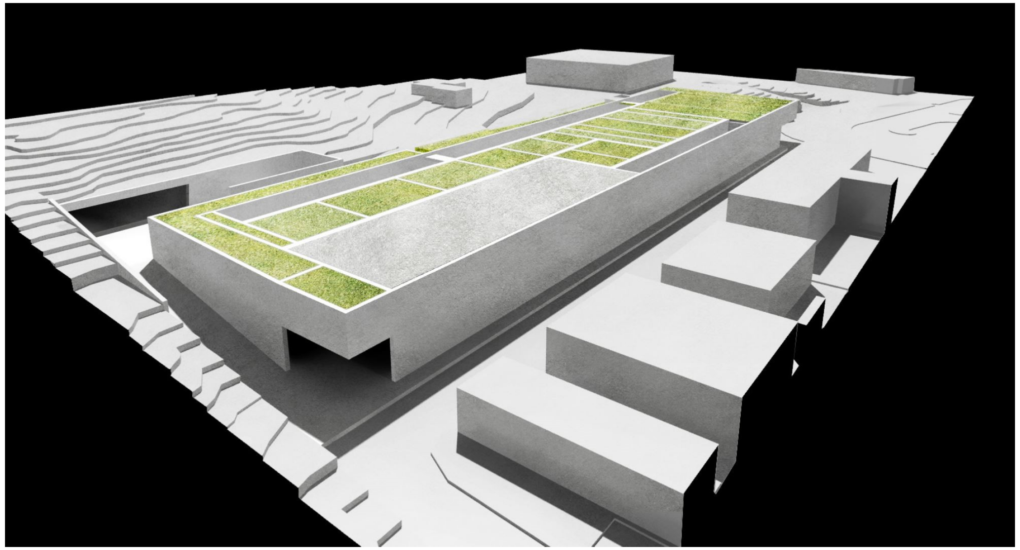
- leveraging on established know-how:
  - beam dynamics
  - beam-plasma-codes



EuPRAXIA@SPARC_LAB conceptual design report arXiv and LNF Publishing
M. Ferrario et al. NIM-A (2018)
A. Marocchino et al. NIM-A (2018)
A. Giribono et al. NIM-A (2018)
C. Vaccarezza et al. NIM-A (2018)
M. Diomede et al. NIM-A (2018)
V. Petrillo et al. NIM-A (2018)

EuPRAXIA@SPARC_LAB

Parameter Choice - pillars	
1 GeV FEL	water window
X-band	compact - research RF tech
plasma acceleration	high gradient acceleration
external injection	highly controllable and tunable



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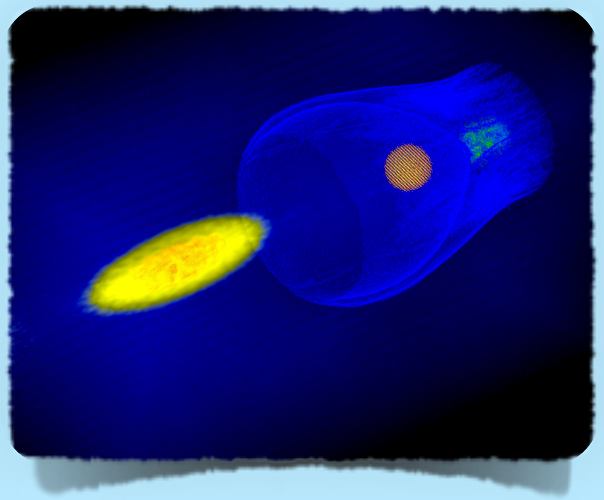
M. Diomede et al. NIM-A (2018)

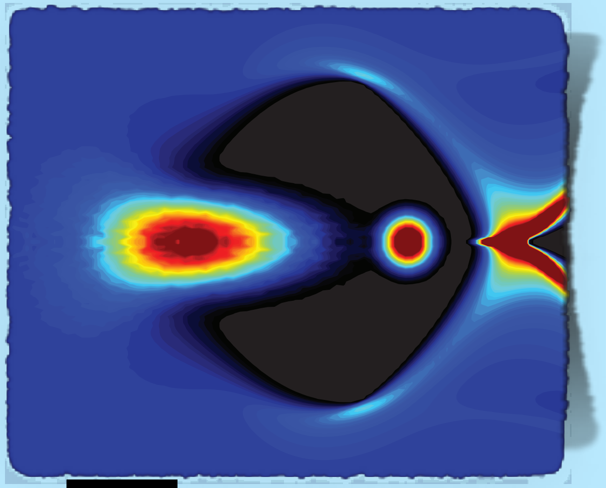
V. Petrillo et al. NIM-A (2018)

Numerical Codes



ALaDyn
full PIC code

bunch and background treated with macro-particles



Λrchitect
hybrid code

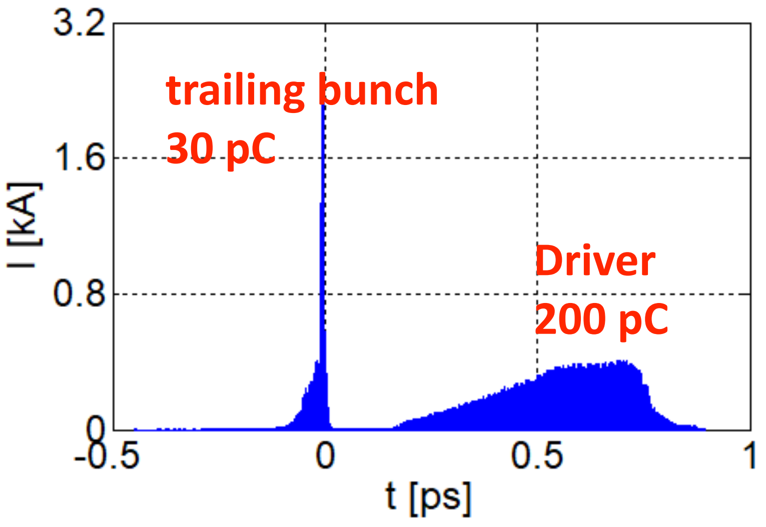
bunch treated as a PIC background as a fluid

Sharing-Chatting via the most modern socials *(please join!)*

A. Marocchino et al. NIM-A (2016)
F. Massimo & A. Marocchino J. Comp. Physics. (2016)
A. Marocchino et al. NIM-A (2018)
A. Curcio & A Marocchino Sci. Rep. (2018)
——————
A. Marocchino et al. APL (2017)
R. Pompili et al. APL (2017)
A. Curcio et al. APL (2017)

bunch generation

bunch currents :: TStep sims



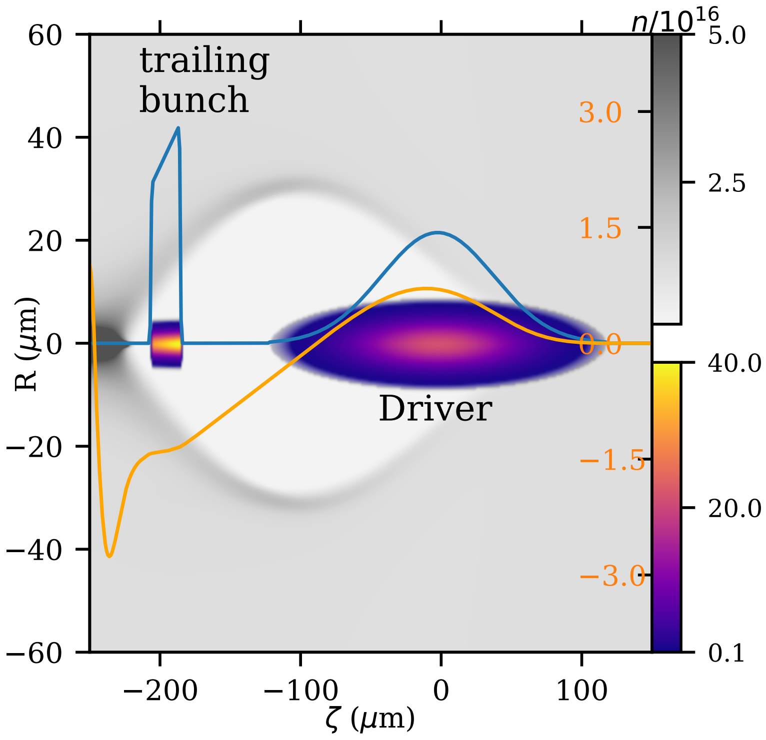
- Trailing bunch triangular shape
- Bunch separation 0.55 λ_p :: accelerating phase
- 2 kA peak current

trailing bunch quality

	Tr. Bunch
Charge	30 pC
Energy	101.5 MeV
RMS Energy	0.15%
σz	3.6μm
peak current	2 kA
εx norm	0.69 mm-mrad

- high brightness bunch
- little deterioration after the comb compressing reversing technique

bunch parameters

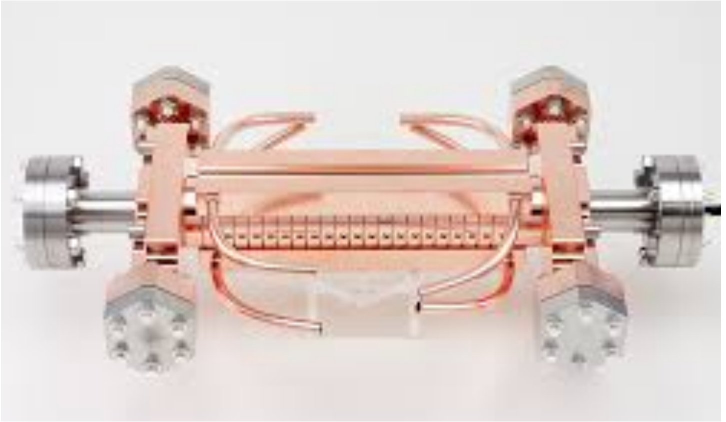


- beam loading compensation

A MAROCCHINO

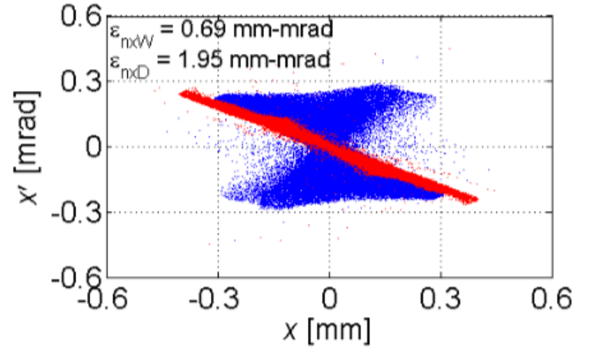
X-band

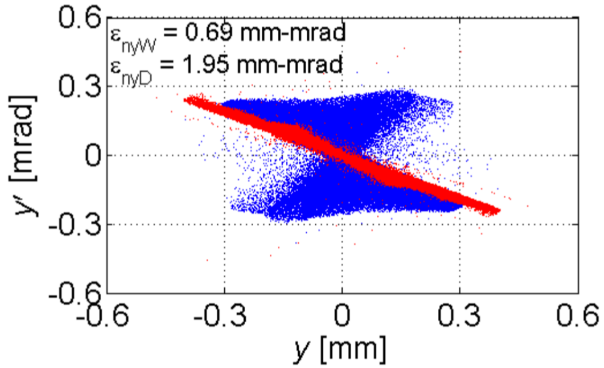
The *X-band* linac



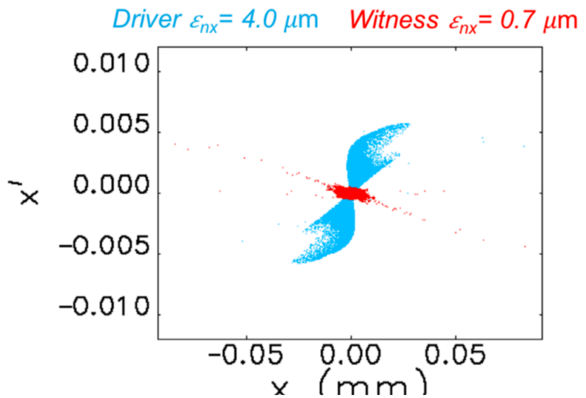
- Accelerating gradient: 60 MV/m
- each section is 50 cm long
- 32 sections
- iris diameter 3.2 mm

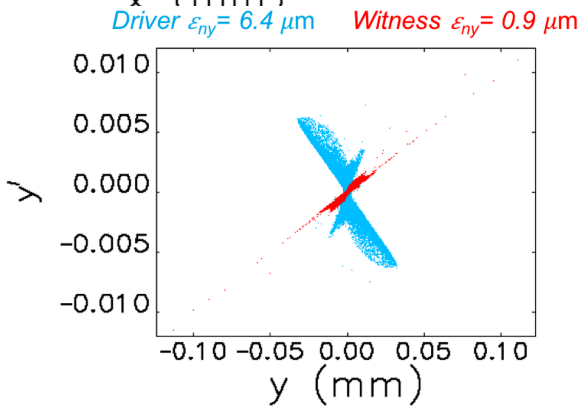
from ~100 MeV





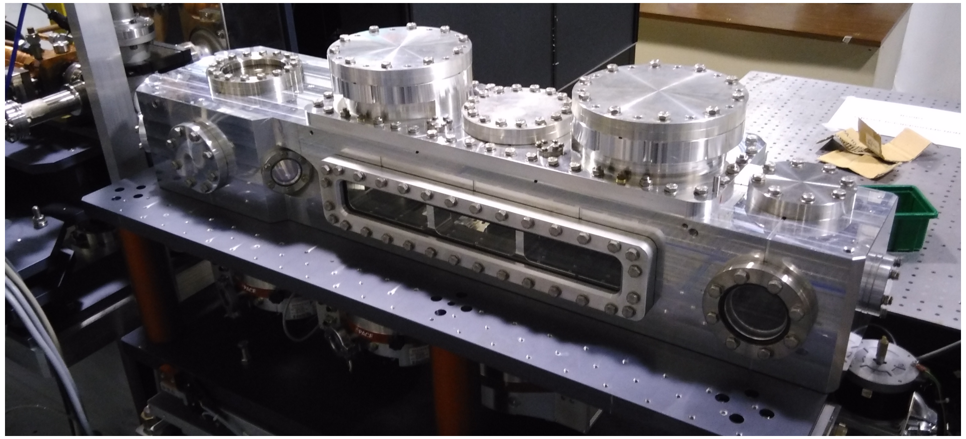
to ~500 MeV

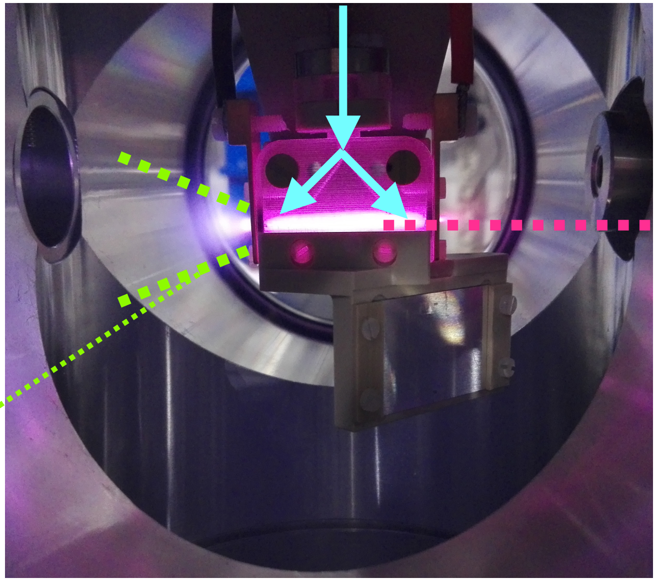




it is difficult to tune the machine for the Driver and the trailing bunch at the same time. Our main focus in the trailing bunch.

plasma acceleration capillary

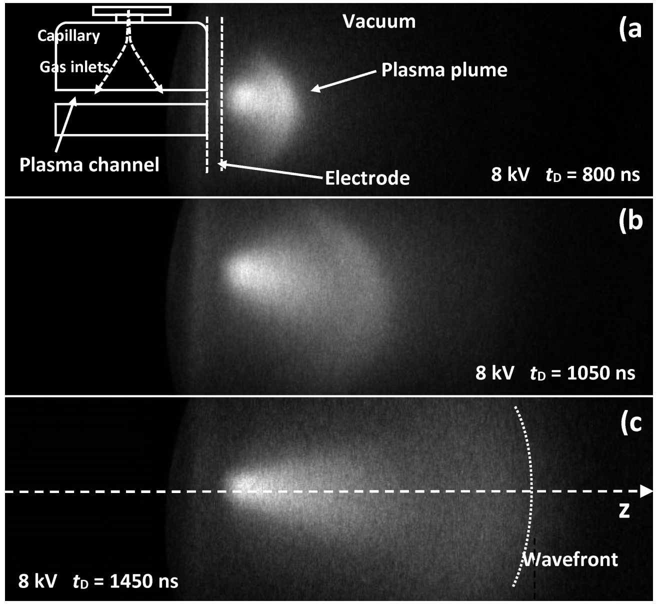




plasma channel

plasma ejecta

plasma ejecta

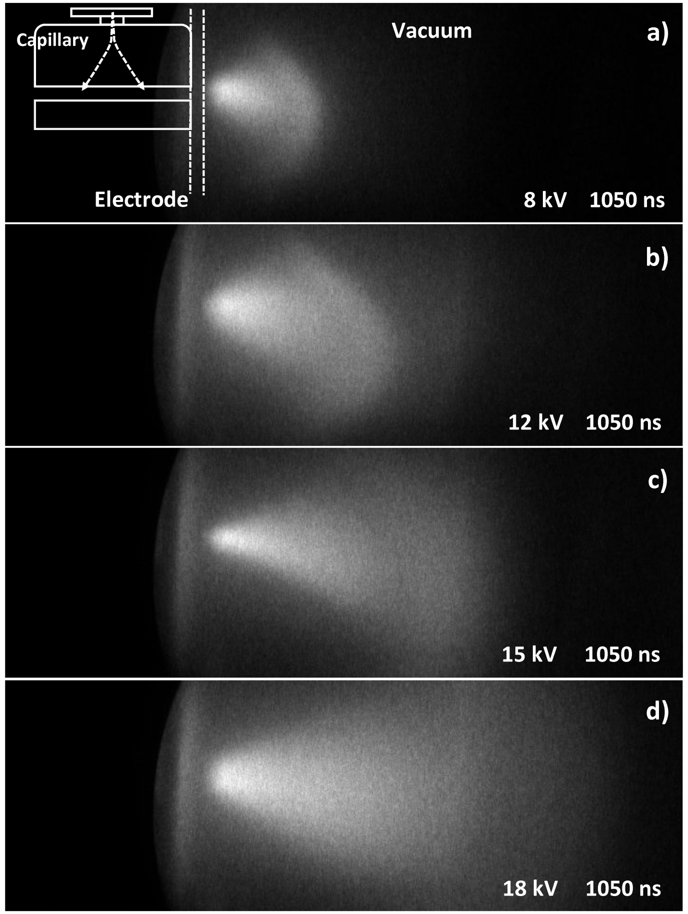


- plasma leakage
- plasma-bema dynamics ramps cannot be neglected

A. Marocchino et al. NIM-A (2018)
A. Marocchino et al. APL (2017)
F. Filippi et al. Rev. Sci. Inst. (2018)
A. Biagioni et al. in prep. (2018)
E. Brentegani & A . Marocchino et al in prep.

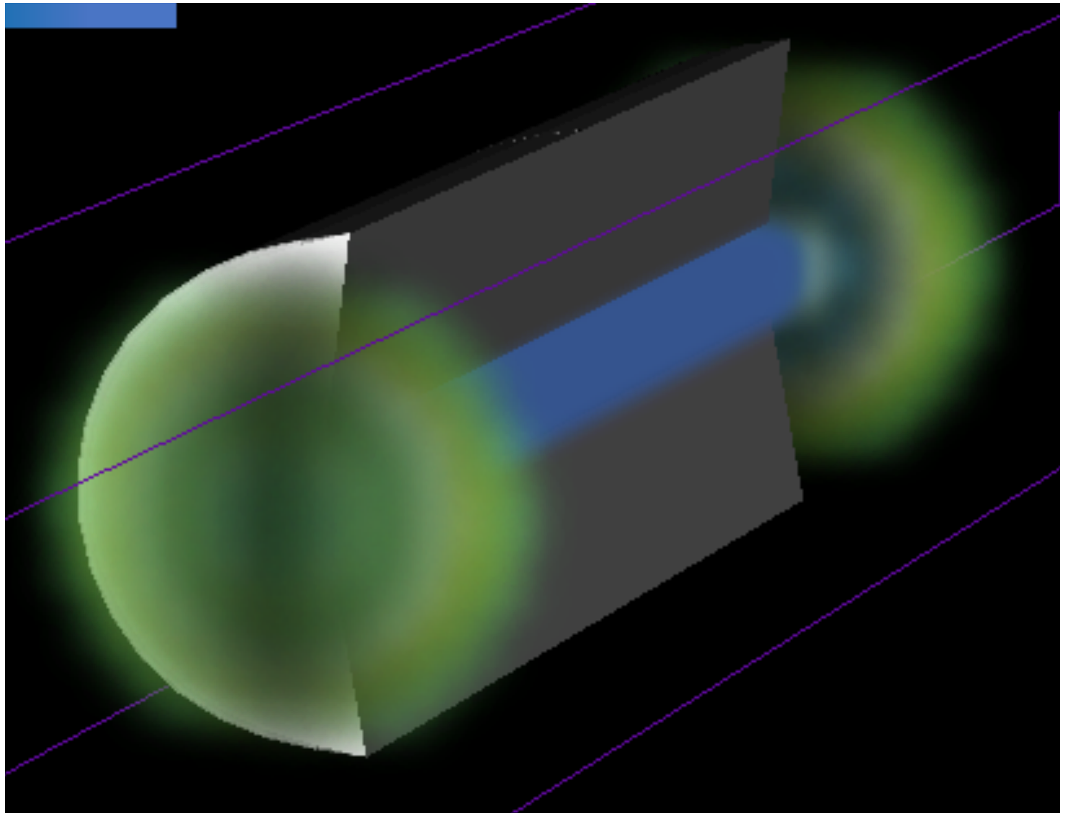
plasma acceleration capillary

experiments



Stark broadening - interferometry

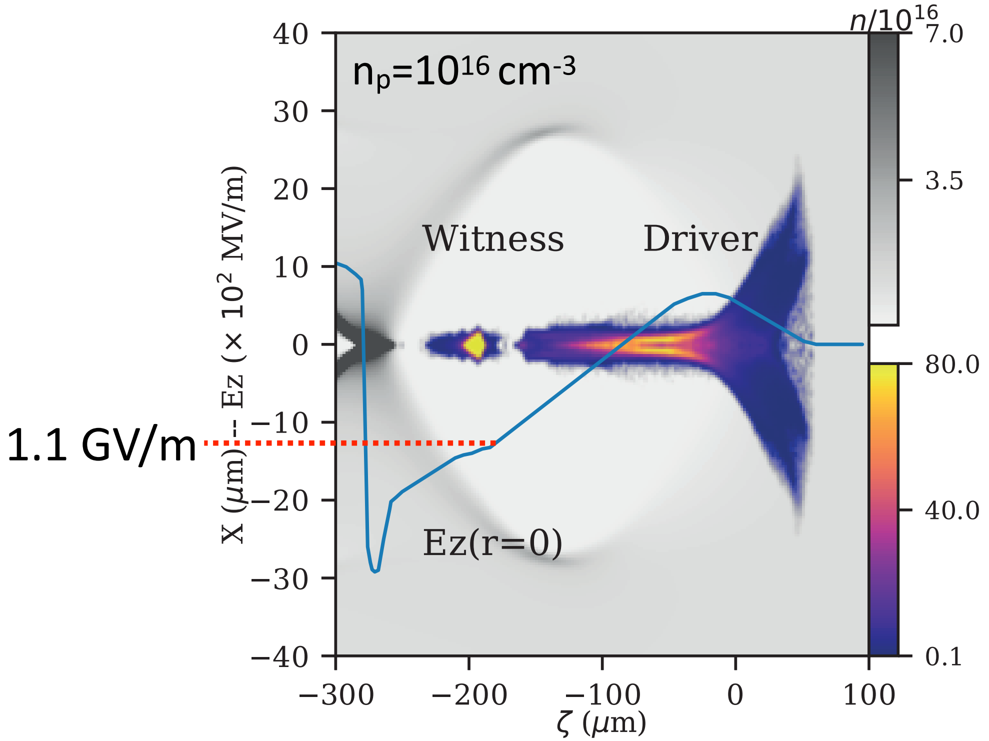
MHD simulations



A MAROCCHINO

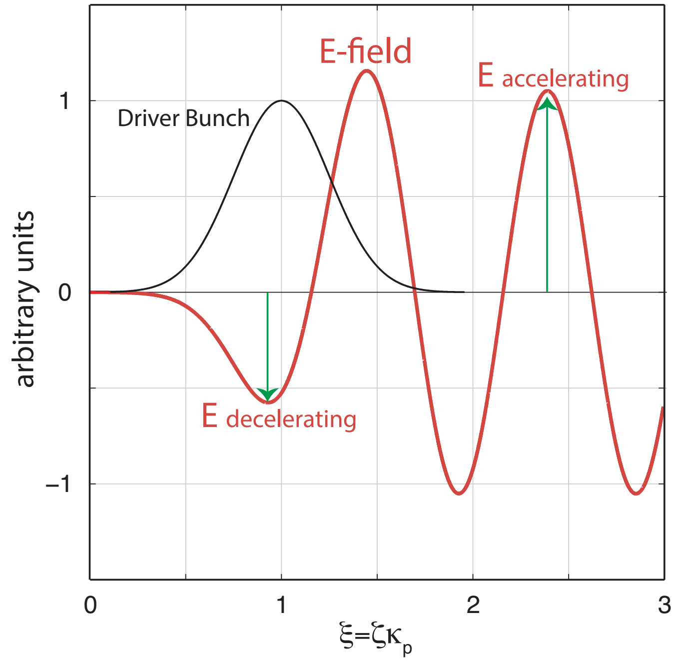
plasma acceleration

plasma acceleration



- density contour plots: bunch density overlaid to background density
- flattening of the accelerating field
- the driver exhibits a expanded head profile

transformer ratio

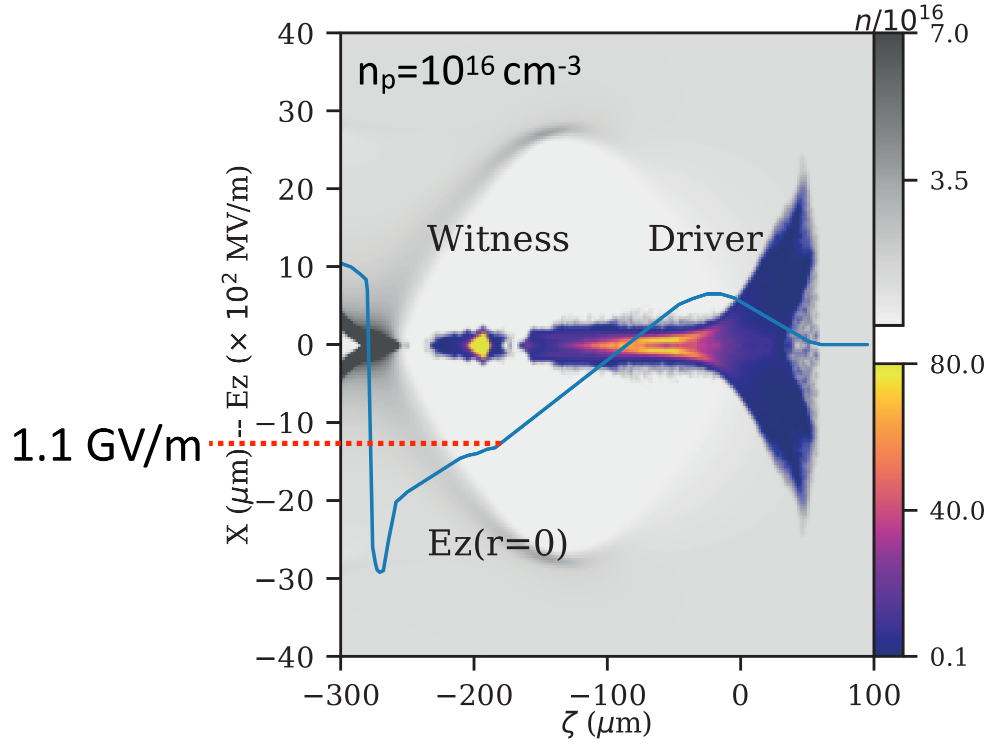


$$R = \frac{E_{acc}}{E_{dec}} \frac{Q_{driver}}{Q_{tr.bunch}}$$

our case R~2.5

plasma acceleration

plasma acceleration



- density contour plots: bunch density overlaid to background density
- flattening of the accelerating field
- the driver exhibits a expanded head profile

plasma injection requirements

extremely close to analytical-matching conditions
leveraging on the RF flexibility to tune the bunch properties

tr. bunch transverse matching ~ 1.8-2 μm

$$\sigma_\perp = \sqrt[4]{\frac{2}{\gamma}}\sqrt{\frac{\varepsilon}{\kappa_p}} \sim 1.5\ \mu\text{m}$$

longitudinal driver length ~ 50μm

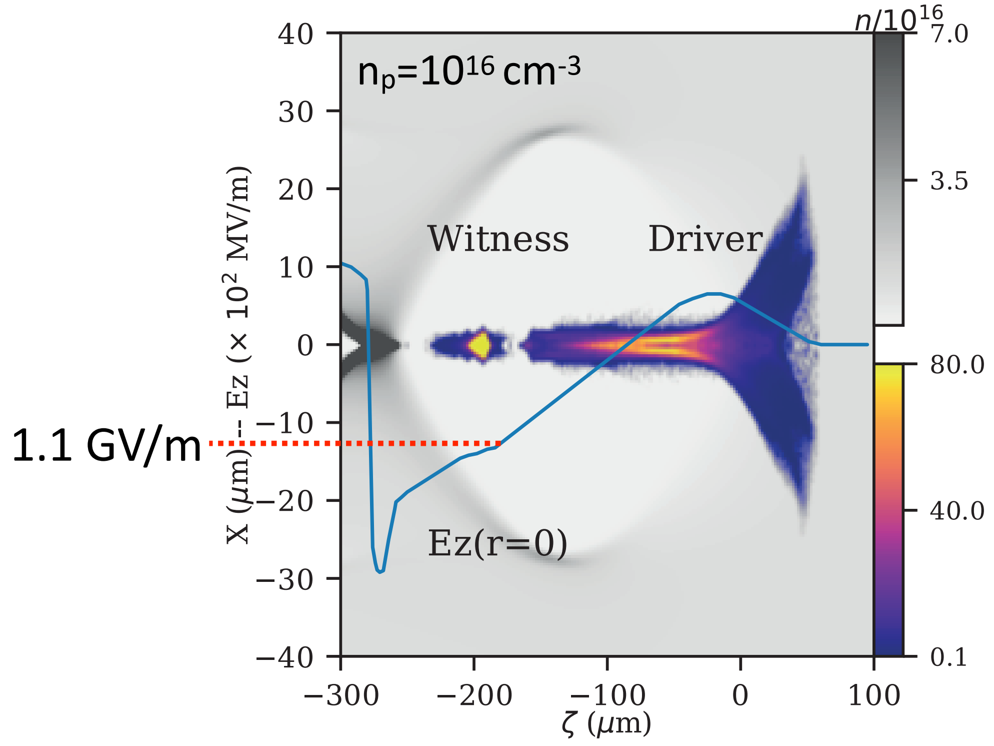
$$\sigma_\parallel = \sqrt{2}/\kappa_p \sim 40\ \mu\text{m}$$

tr. bunch charge ~ 30 pC

$$Q_{\text{witness}} \propto \frac{R^4_{\text{bubble}}}{E_t} \sim 30\text{pC}$$

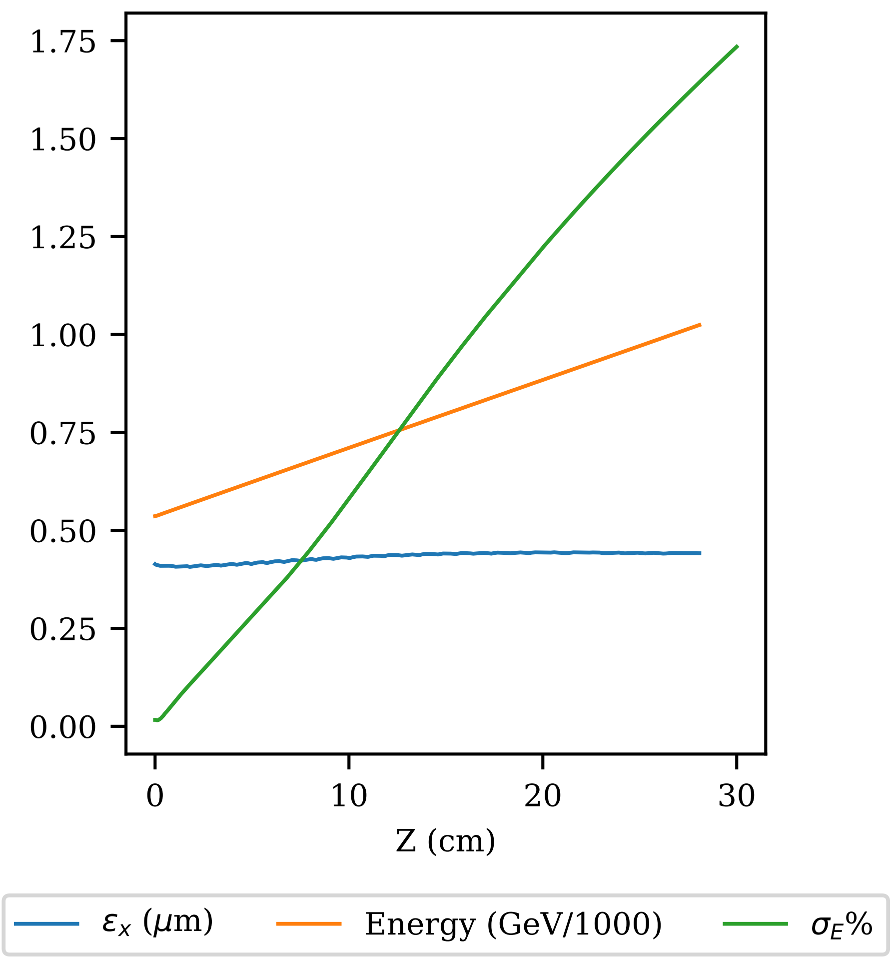
plasma acceleration

plasma acceleration



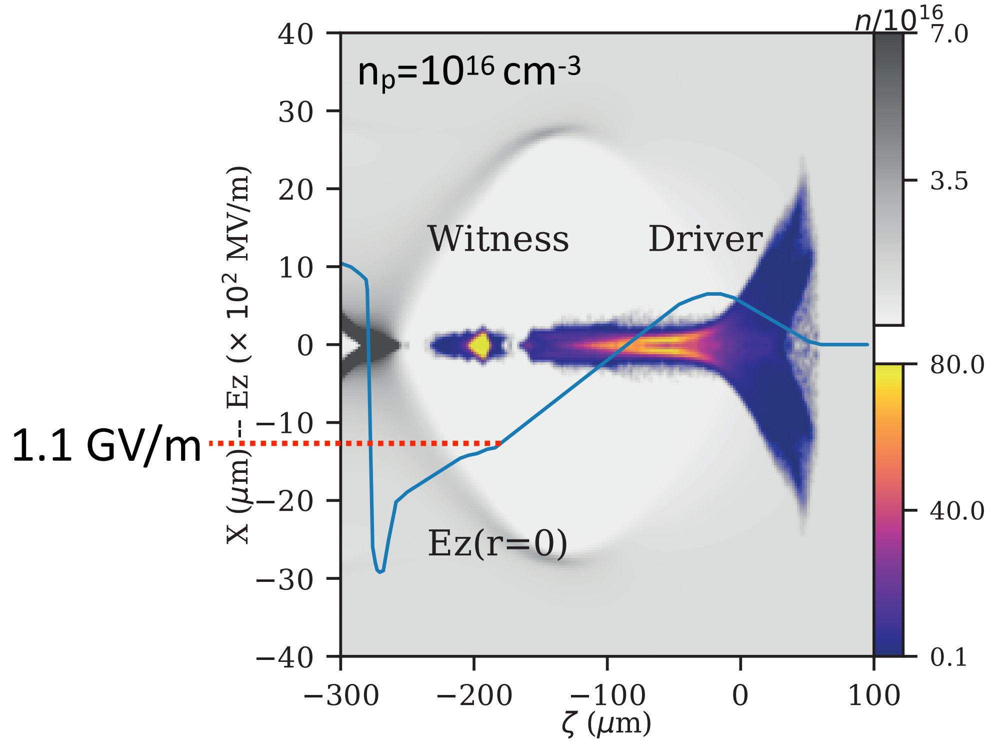
- density contour plots: bunch density overlaid to background density
- flattening of the accelerating field
- the driver exhibits a expanded head profile

integrated parameters



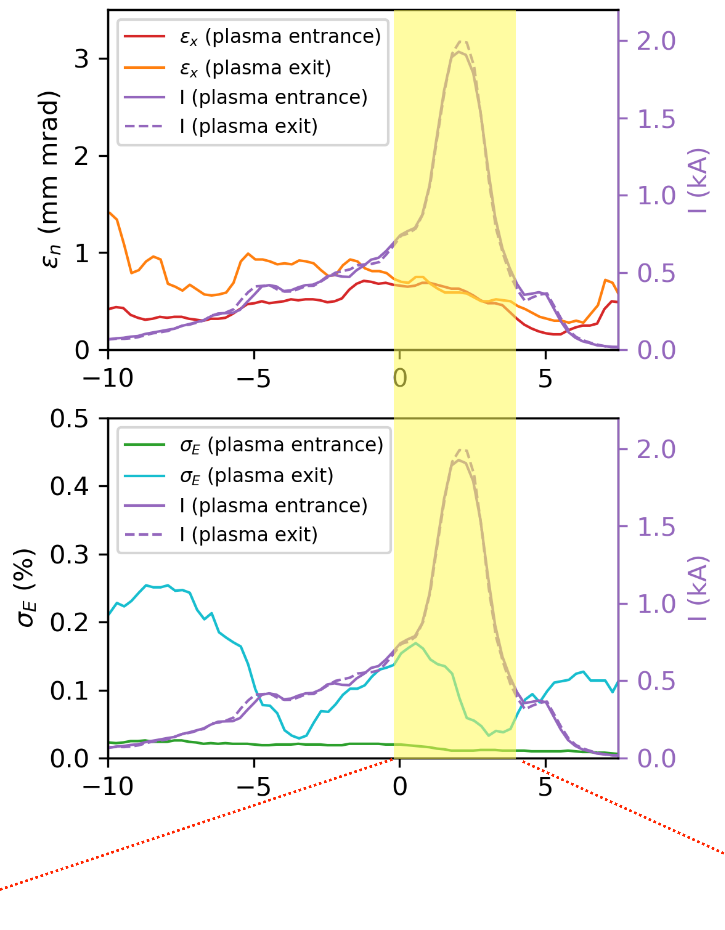
plasma acceleration

plasma acceleration



- density contour plots: bunch density overlaid to background density
- flattening of the accelerating field
- the driver exhibits a expanded head profile

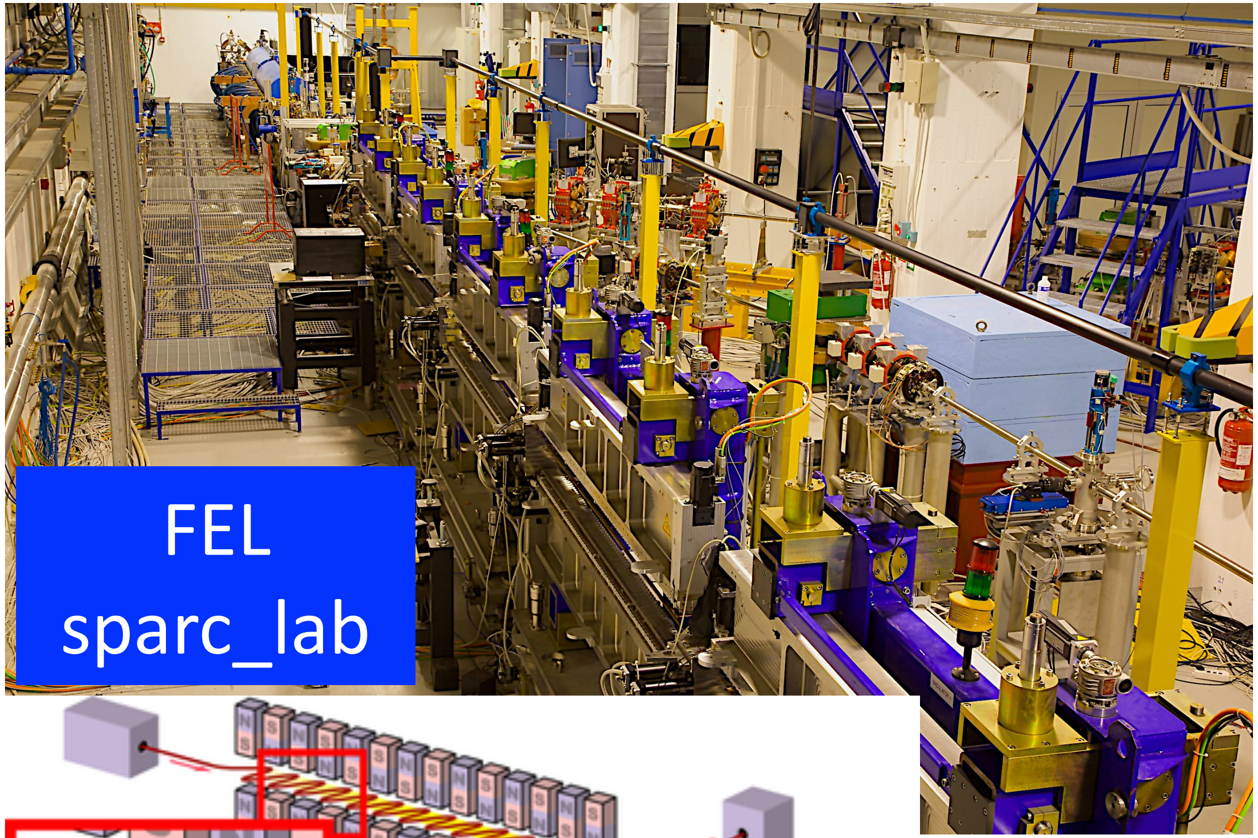
slice analysis

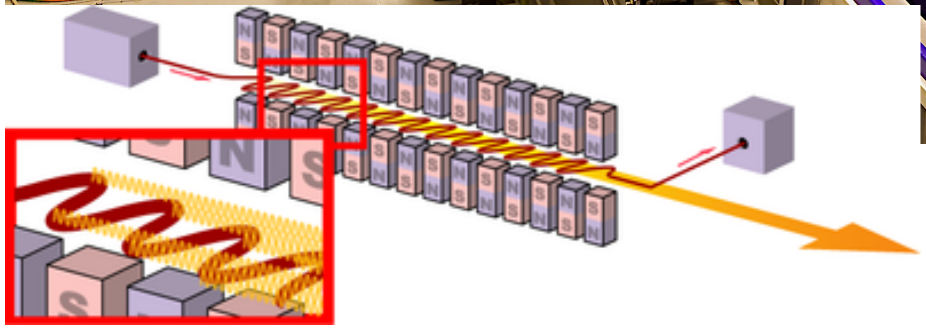


retaining high sliced quality in the peak current region

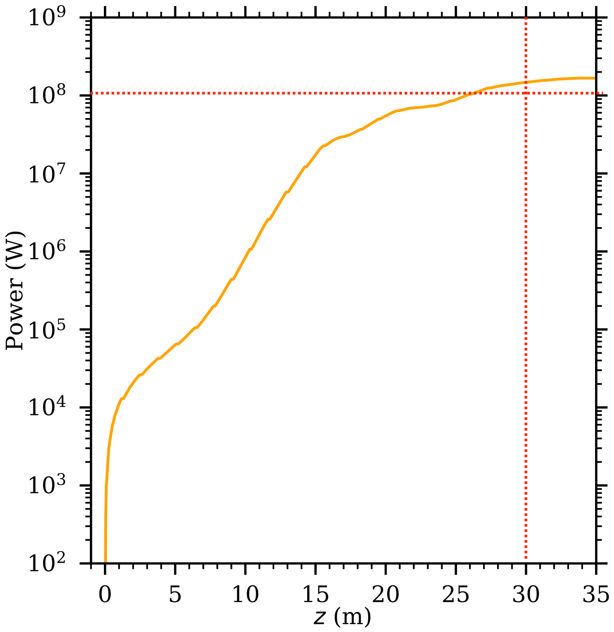
Free Electron Laser

SPARC_LAB FEL



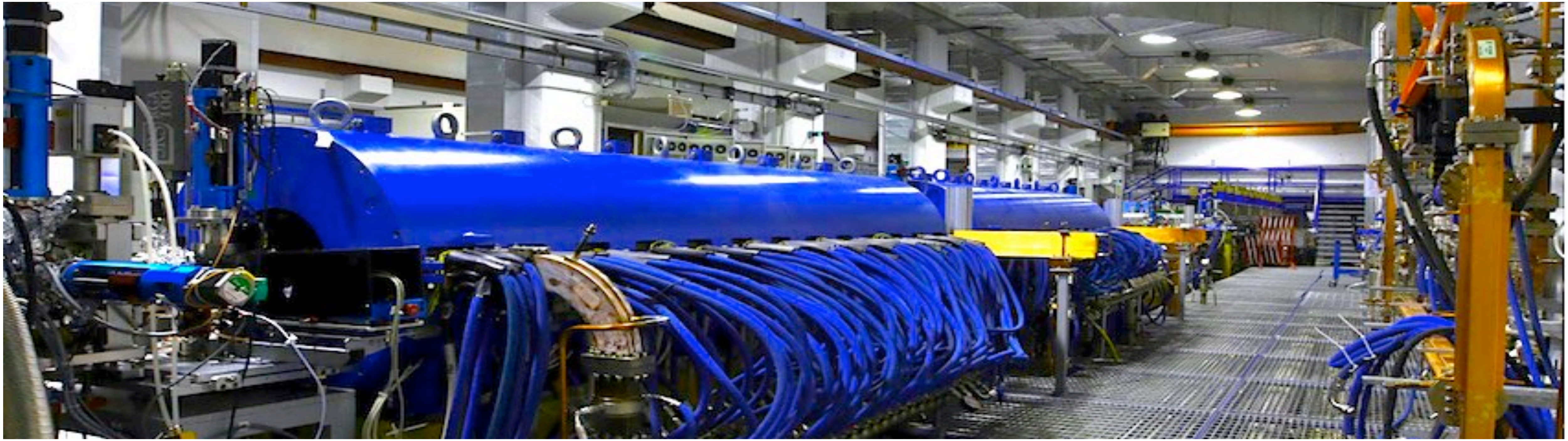


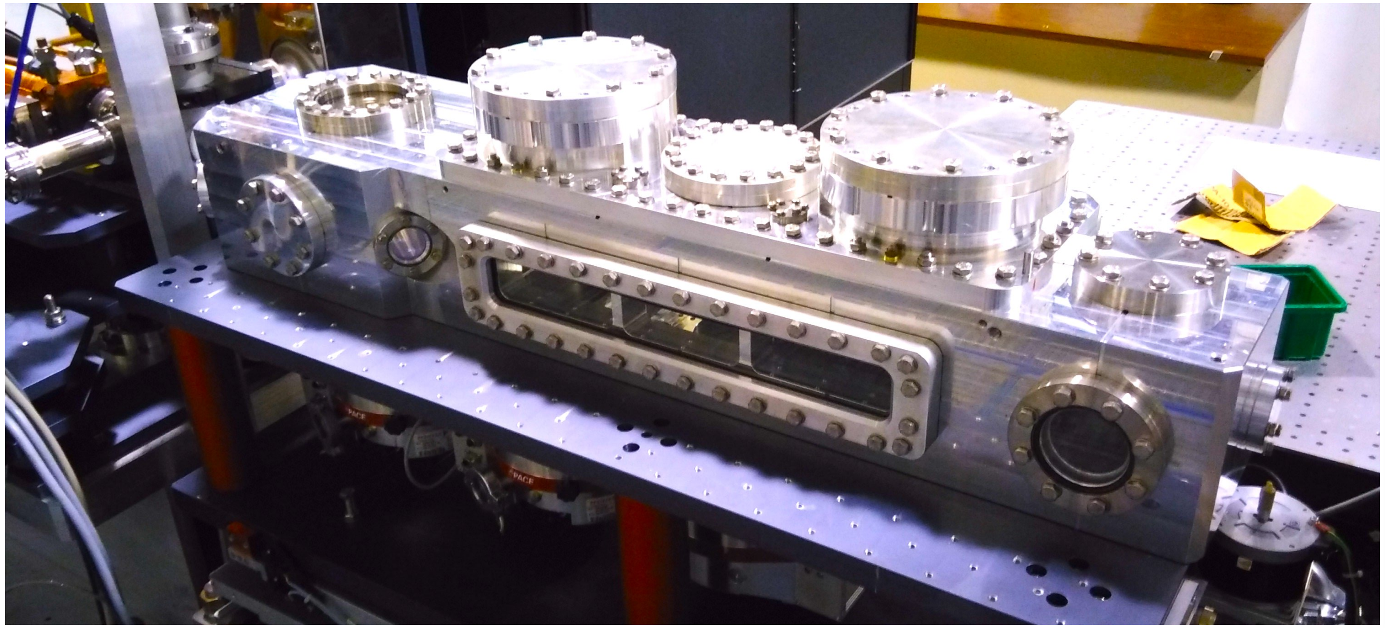
FEL performance



- a_w=0.8
- λ=3 nm
- saturation length 30 m
- 9.76 10^{10} photons per shot
- Power :: 10^8 Watt

V. Petrillo et al. NIM-A (2018)





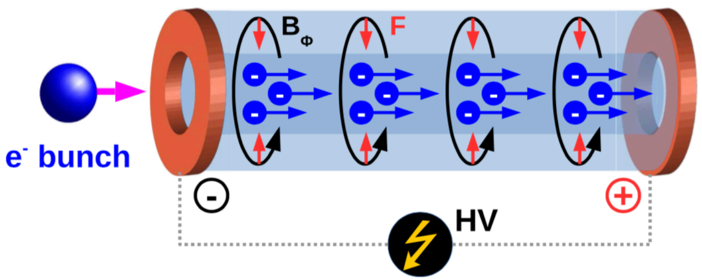
SPARC_LAB

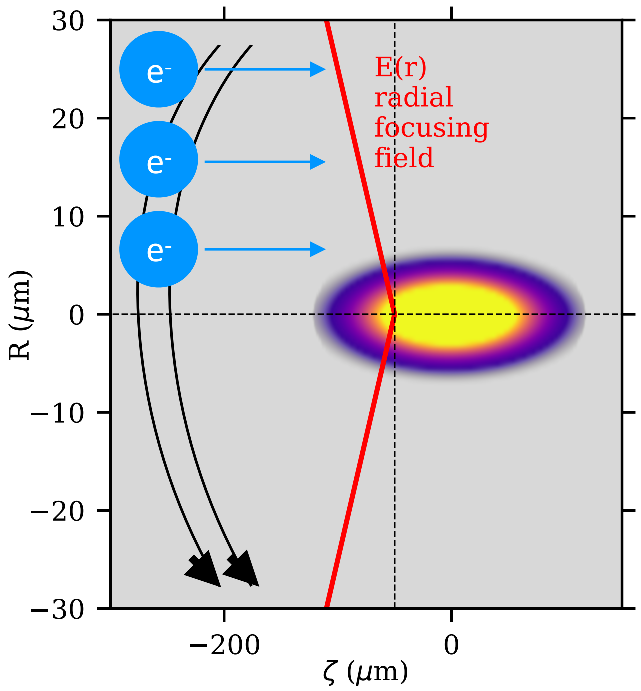
Frascati

Italy

plasma lenses

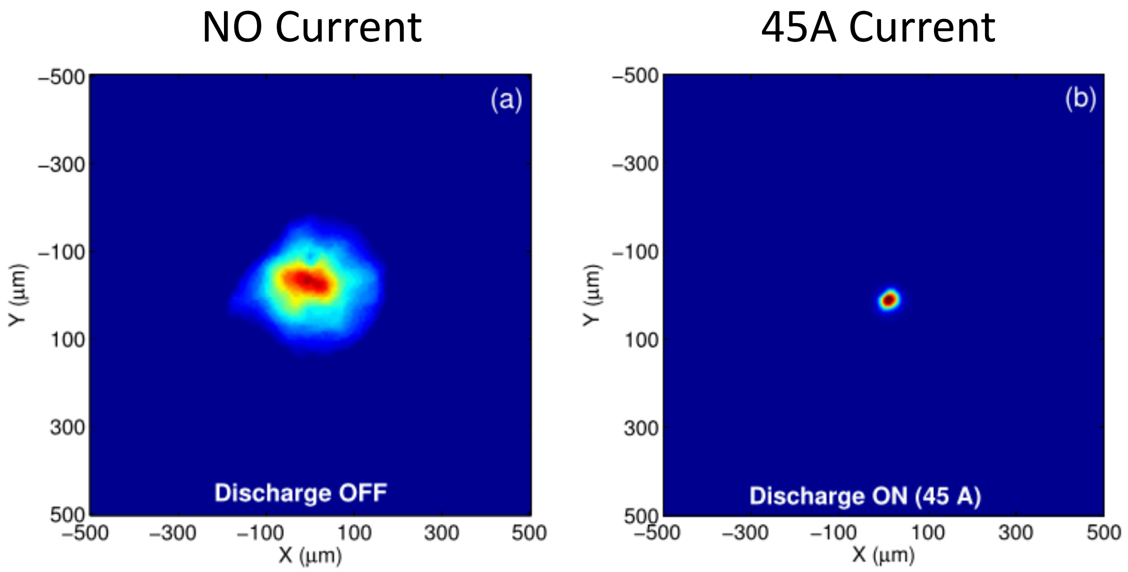
active focusing mechanism





the motion of the background electron produces a **poloidal-focusing field**

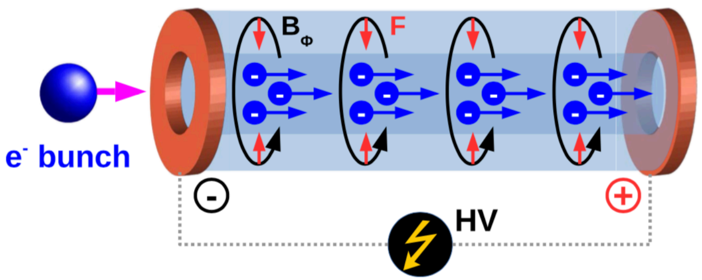
active focusing

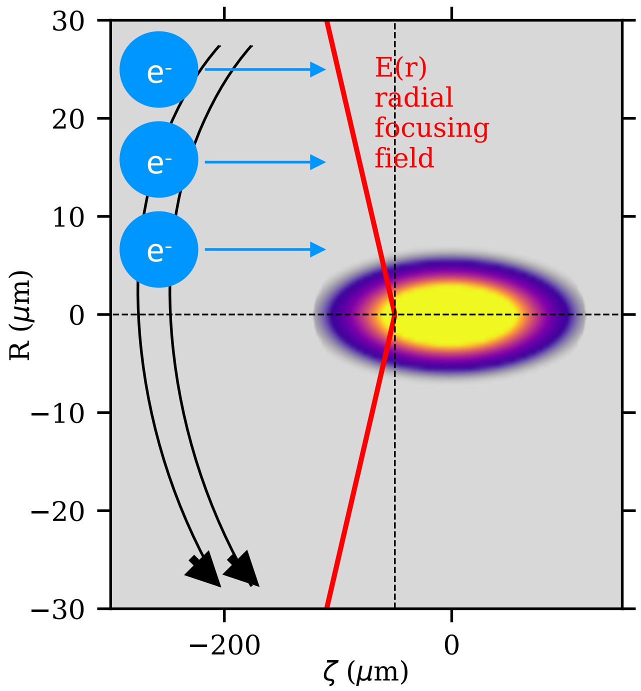


A. Marocchino et al. APL (2017)   R. Pompili et al. APL (2017)

plasma lenses

active focusing mechanism

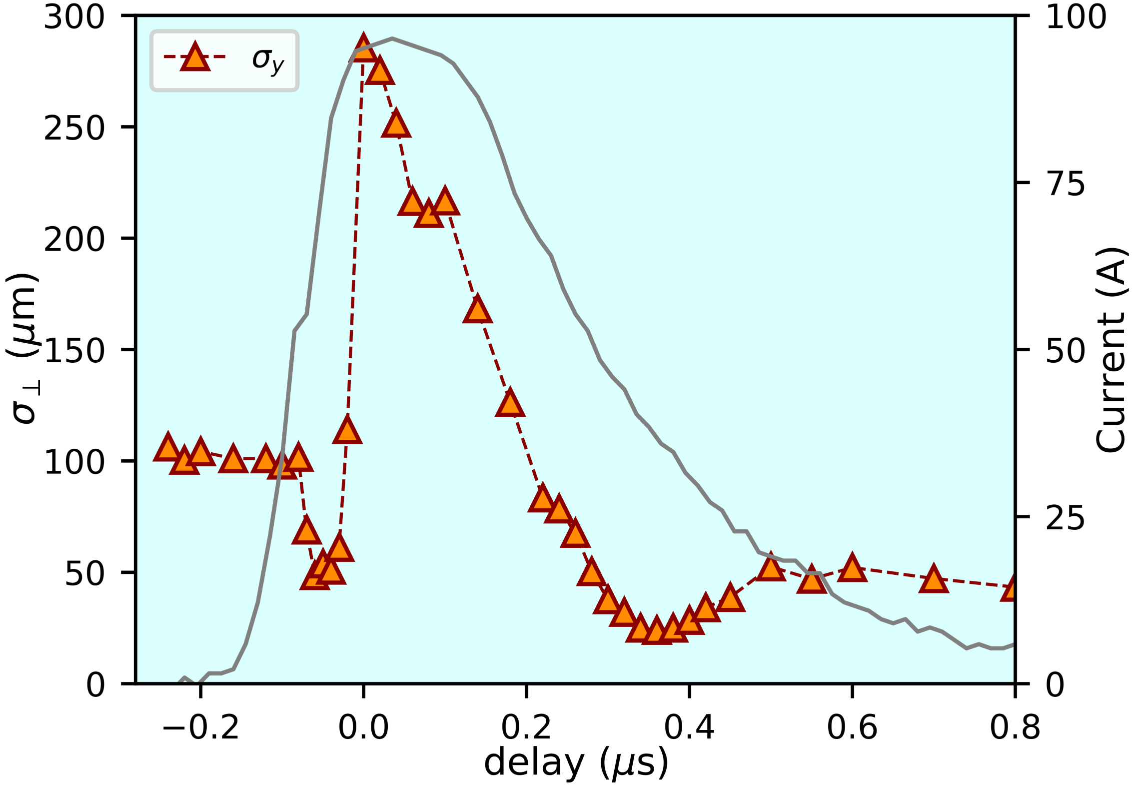




the motion of the background electron produces a **poloidal-focusing field**

experimental results

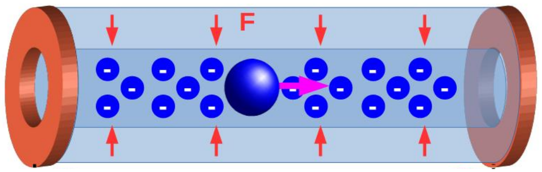
beam transverse dimension *on monitor*

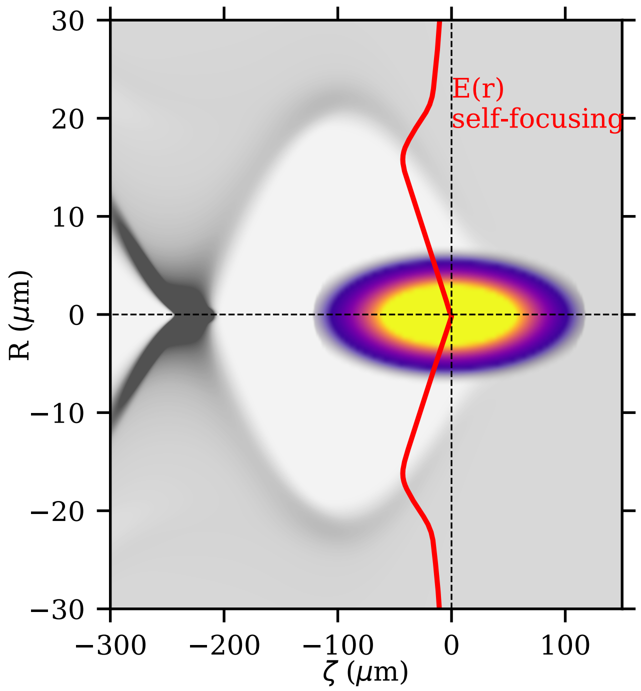


A. Marocchino et al. APL (2017) R. Pompili et al. APL (2017)

plasma lenses

passive focusing mechanism





the motion
of the background electron
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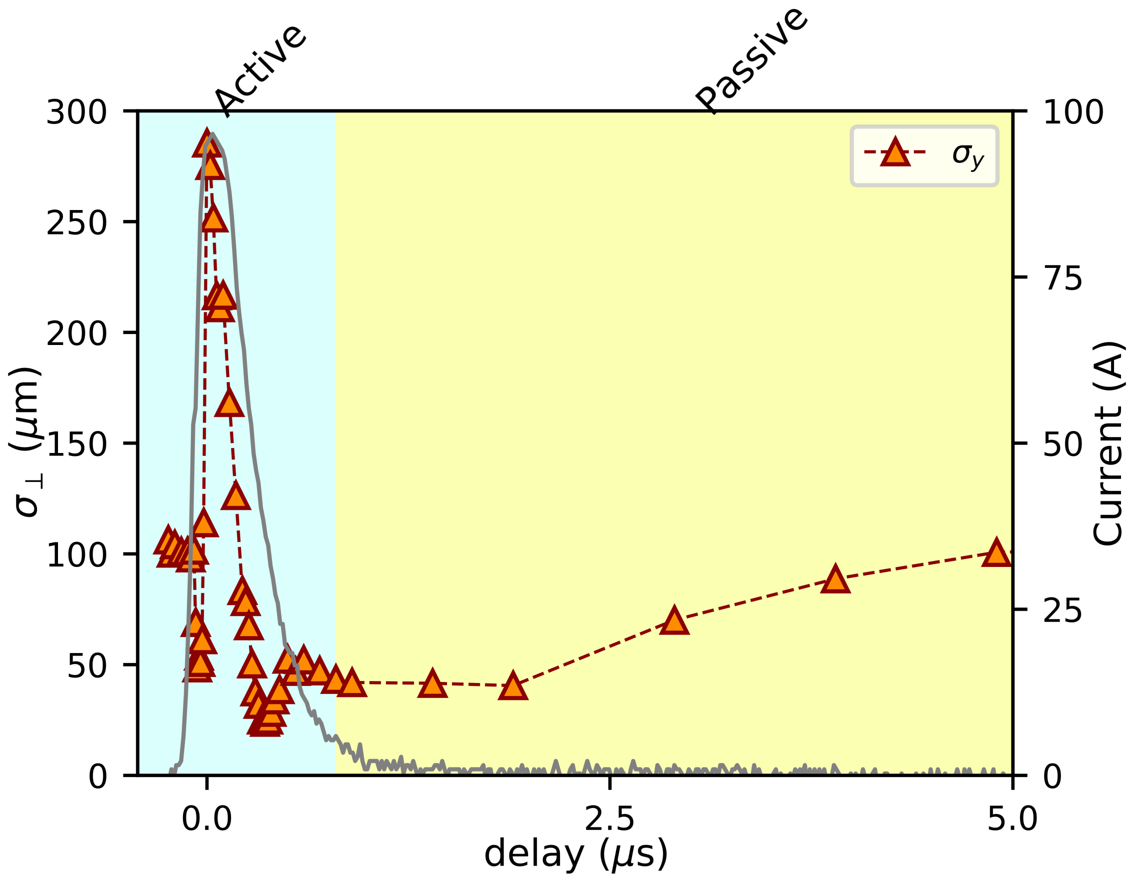
experimental results

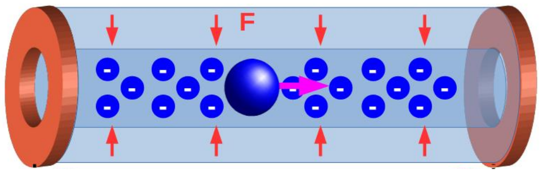
beam transverse dimension *on monitor*

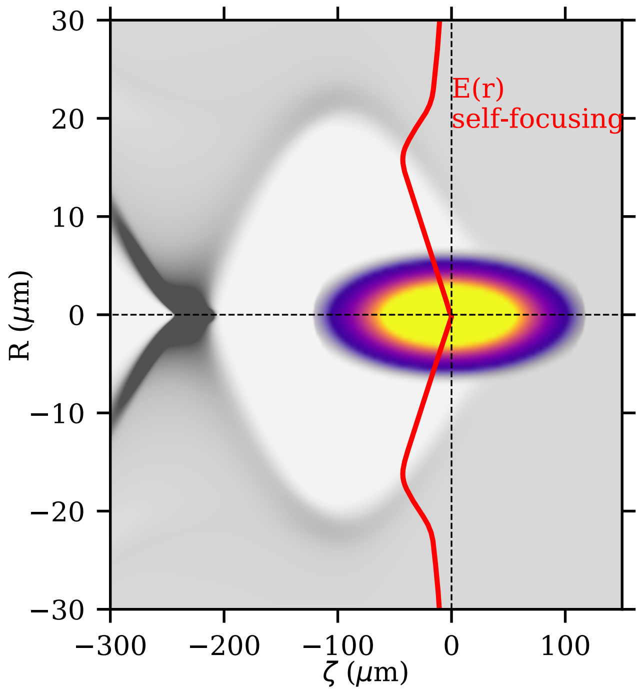


A. Marocchino et al. APL (2017) R. Pompili et al. APL (2017)

plasma lenses

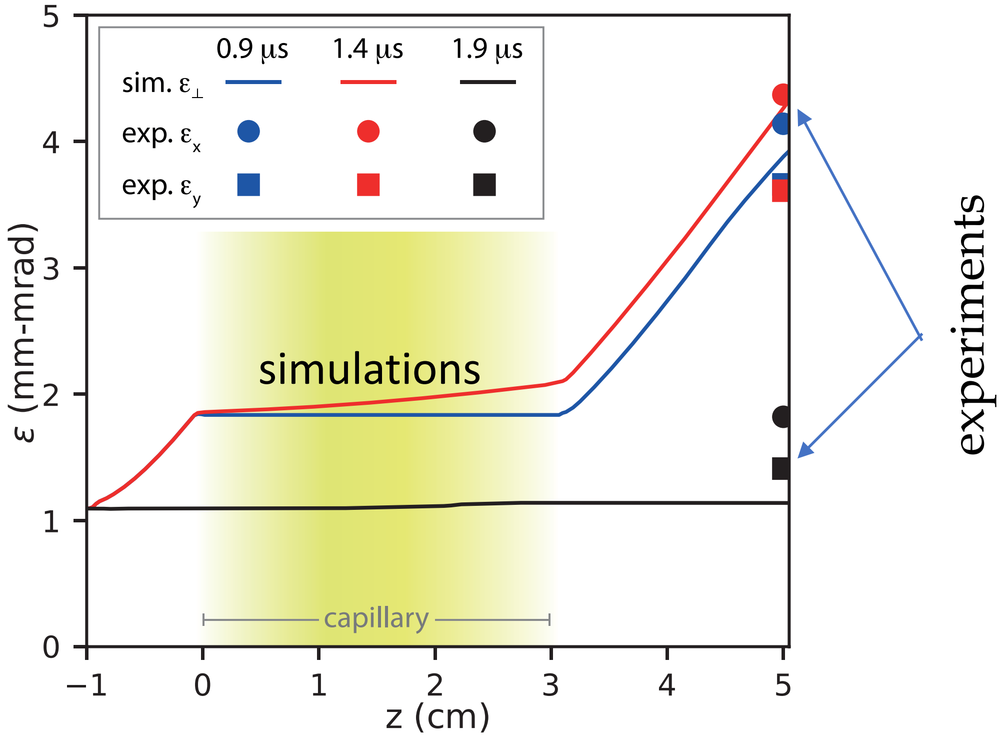
passive focusing mechanism





the motion
of the background electron
produces
a **poloidal-focusing field**

Experiments VS simulations

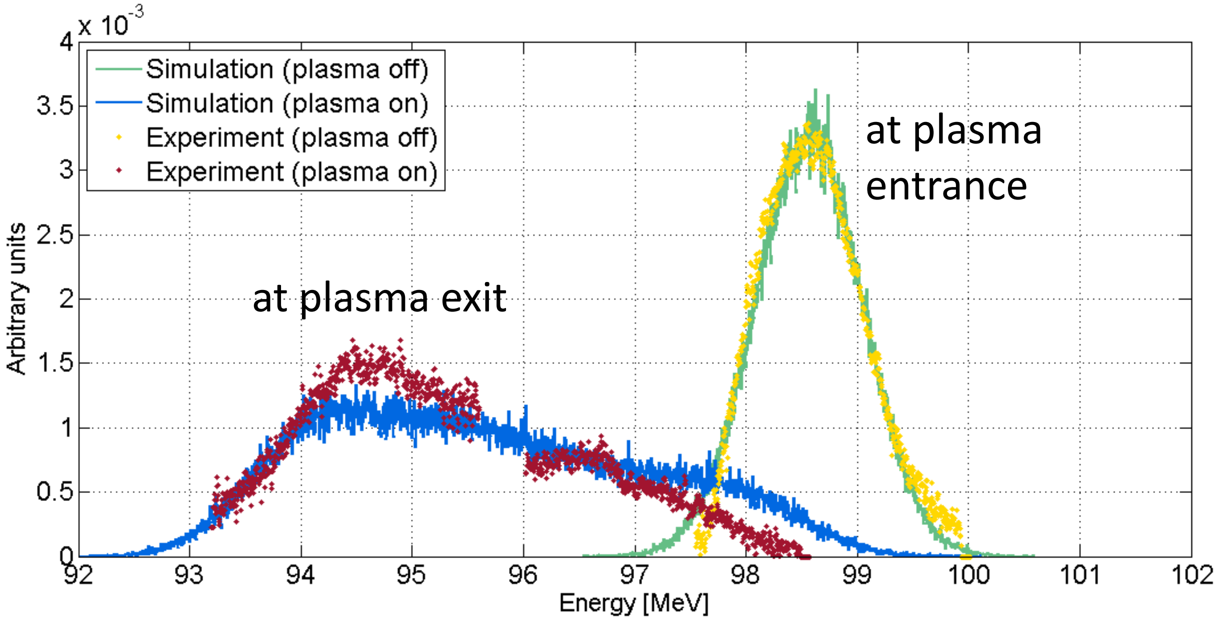


quality degradation for long bunches and densities higher than bunch density

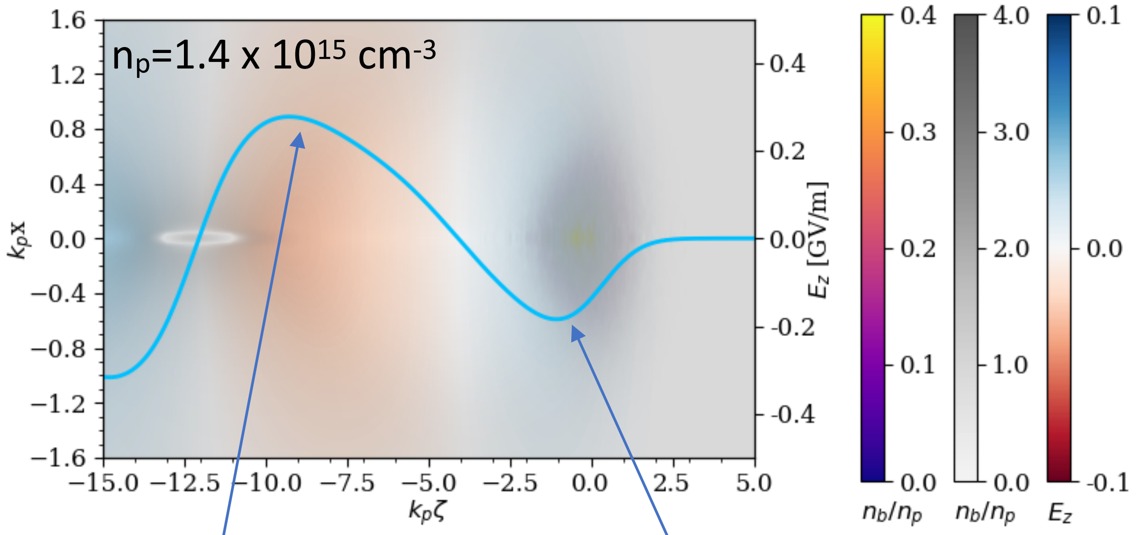
A. Marocchino et al. APL (2017)   R. Pompili et al. APL (2017)

deceleration experiments

plasma deceleration - SIM Vs EXP



max E-field



$Ez_{accelerating}$ >300 MV/m

$Ez_{decelrating}$=200 MV/m

CONCLUSIONS

- A realistic simulation:
  - from the Photo-injector
  - throughout a Plasma Accelerating Section
  - to seed a FEL
  - simulations supporting the upcoming EuPRAXIA@Sparc_Lab facility

- 1.1 GV/m + quality preservation + FEL seeding

- EuPRAXIA@SPARC_LAB an ongoing project!

- New results at SPARC_LAB from Plasma lenses to Plasma deceleration